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Survey Courses in the Natural Sciences

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THE purposes of this paper are to present data concerning college survey courses in the physical and biological sciences, to present an analysis of these courses, and to point out the advantages and disadvantages which are attributed to them.

At the outset we must define what we mean by a survey course. Our definition will be stated in terms of intent as well as content. A survey course is any course intended for college freshmen and sophomores primarily as part of their general education, which draws its subject matter from two or more of the ordinary college departments. It is desirable to add that a survey course is one which is planned as part of the general education of college freshmen and sophomores who will not necessarily become scientists, in order to distinguish between the courses which we shall discuss and the survey or coordinating course given in some colleges for upper division students who are majoring in science, and also in order to distinguish between survey courses and the general biology course now taught in many colleges; this general biology course is a combination of zoology and botany, and is intended partially as a foundation for specialization in the field of biological science. The stipulation that a survey course must draw its content from two or more of the ordinary college departments is useful in distinguishing between such courses and the elementary courses in certain special departments, as physics, chemistry and zoology, which are also in one sense "survey courses" in that they cover a field which is divided into specialized areas for study at the intermediate and upper college levels. It is important to note that we are omitting from consideration the "cultural" courses in separate sciences, which sometimes go under a name such as "survey of physics." These courses are designed for the purposes of general education, but they are different enough from the survey courses that form the subject of this paper to deserve separate treatment. Finally, this paper is limited arbitrarily to a consideration of survey courses that devote at least four semester hours to the natural sciences in general, or two semester hours to physical or biological science. This eliminates a considerable number of the "orientation" type of courses, which, however, do not as a rule satisfy the science requirement for a B.A. degree and therefore do not provide the major share of a student's general education in science.

In spite of all these restrictions placed upon the meaning of the term "survey course" for the purposes of this paper, there remains a great variety of courses for our consideration. It will become evident that no blanket judgment can fairly be made upon a set of courses that present so wide a diversity of purpose and method.

STATISTICS CONCERNING SURVEY COURSES

The data given in Table I were obtained by Miss Edna Blackwood from a study of 517 liberal arts college catalogs, of which 220 contained announcements for the year 1935–1936, 208 for 1934–1935, and 89 for years previous to 1934.

TABLE I. *Science survey courses in liberal arts colleges—1935.**

Courses in	Semester hours credit 2	3	4	6	8	10	Totals
Natural sciences							
Total number			6	12	2	2	22
Required of most students			4	7	1	2	14
No. with lab. work					1	1	2
Physical sciences							
Total number	2	4	6	9	10	3	34
Required of most students	2	3	3	2	4	1	15
No. with lab. work	1	1	1	1	2	1	7
Biological sciences							
Total number	1	5	6	6	7	2	27
Required of most students	1	4	3	4	2	1	15
No. with lab. work		2	3		3	1	9
Totals	3	9	18	27	19	7	83

* These courses are distributed among 64 liberal arts colleges. Courses of the "orientation" type that devote less than 4 semester hours to all of the natural sciences have been omitted, because they do not as a rule satisfy the science requirement for the B.A. degree. Survey courses classified under "Natural sciences" are those in which material from biological and physical science is included in a single course; within such courses the individual sciences may or may not be allotted discrete blocks of time. Courses grouped under "Physical sciences" generally include material from astronomy and geology as well as from chemistry and physics; those classified under "Biological sciences" include material from human physiology and in some cases from psychology, in addition to material from botany and zoology.

She found that 64 liberal arts colleges are offering natural science survey courses. The Educational Directory for 1935 lists 644 colleges and universities. The data in Table I therefore represent a number which I should estimate at 10 or 15 less than the number of survey courses actually now in existence in liberal arts colleges. In addition, the Educational Directory lists 238 teachers colleges and normal schools, 426 junior colleges, and 107 Negro colleges. Natural science survey courses are more common in teachers colleges than in liberal arts colleges. Although we have no carefully studied data from teachers college catalogs, a record of such courses in 20 teachers colleges is available, and this, together with a list of such colleges using a certain popular textbook for survey courses, gives a basis for a conservative estimate of about 50 teachers colleges giving survey courses in the natural sciences. Six Negro colleges are known to give science survey courses, and I doubt that there are more than two or three others. There is a record of survey courses in 8 junior colleges, and I would make a conservative estimate of 15 such courses in the junior colleges.[1] After summing up these figures, I estimate the total number of institutions of higher education offering survey courses in the natural sciences to be in the neighborhood of 150.

Survey courses are at present increasing in numbers. Not quite ten years ago a study of the programs of approximately 300 colleges made by Fitts and Swift[2] showed that in 1926 there were about 5 natural science survey courses in these colleges. In 1931, on the basis of a study of college catalogs, I estimated that there were about 15 liberal arts colleges giving natural science survey courses. Thus very few survey courses are more than two or three years old, and a considerable number of them are being given for the first time this year. I know of only three or four survey courses that have been started and then dropped.

ANALYSIS OF SURVEY COURSES

In attempting to arrive at an understanding of survey courses, it is important to realize that there are several varieties, even within the limits set by our definition. They represent the attempts of several hundred teachers with different talents to use the subject matter of natural science as they understand it for the purposes of general education as they see it.

Reference to Table I will show that there are three types of courses when classified according to administrative plan. Where a single survey course in natural sciences is given, material from all the physical and biological sciences is included in the course. The various special sciences may be presented separately by specialists in the separate fields, or there may be some such integration of subject matter as will be described below. The typical natural science survey course is a 3-hour course which continues for two semesters. This is also the typical teachers college survey course, though data from teachers colleges are not included in the table. Survey courses in physical or biological sciences usually carry 2 to 4 credits for two semesters. Thus we can see that there is one

[1] A part of the information used in this paper was obtained from an unpublished study of the returns to a questionary on survey courses sent out by the editors of the *Journal of Higher Education*.

[2] C. T. Fitts and F.H. Swift, *The Construction of Orientation Courses for Freshmen*, Univ. of Calif. Publications in Educ. **2**, No. 3 (1928).

group of colleges which devotes about 6 semester hours to general education in natural science, and another group which devotes 12 or 16 hours, divided between courses in physical and biological science, to the same purpose.

The most significant analysis of survey courses grows out of a consideration of the way in which their subject matter is treated. Here we must distinguish between *emphases* rather than between definite types of courses. There are courses with the following characteristic emphases.

Comprehensive courses. Perhaps the majority of survey courses, as the name suggests, give an extensive survey of the topics within some broad field of knowledge. They are encyclopedic in character. Such courses may be divided into sections under the guidance of specialists in separate subjects, as at Chicago, where the students can say, "We commence physics next week." The tendency in these courses is to use with slight modification the form of organization of subject matter that is found in the separate subject fields. Examples of comprehensive courses are those in physical and biological sciences at Chicago, in human biology and in physics and chemistry at Minnesota, in physical sciences at Colgate, in physical and biological sciences at Georgia, and in natural sciences at Stephens College.

Selective courses. A selective course is one in which a small number of topics or principles form the framework, the subject matter pertaining to them being drawn from different science fields. No attempt is made to "cover the ground" of the various sciences. The subject matter of a selective course may be chosen largely on the basis of what seem to be the most pressing student needs and interests, as in the biological science course at Colgate; or it may be chosen to illustrate some important theme, as in the Evolution course at Dartmouth and in the Basic Wealth course at Minnesota. Those who have read the *31st Yearbook of the National Society for the Study of Education*,[3] entitled "A Program for Teaching Science," will be familiar with the idea there presented of organizing the science curriculum for the purposes of general education about broad generalizations which ramify widely into human affairs. Such generalizations, for example—the sun is the chief source of energy for the earth—, I shall call "interpretative generalizations" to distinguish them from "pure science generalizations" which are designed to extend knowledge in the fields of natural science. A course organized about interpretative generalizations is a selective survey course. Three teachers of the Colorado State Teachers College at Greeley have combined to write a textbook for such a course, which is widely used especially in teachers colleges. The physical science teachers at Pasadena (California) Junior College are developing a course of this type.

The selective course is to be contrasted with the comprehensive course. The former is not a survey course in the strict sense, but the name is now usually applied to selective and comprehensive courses alike. The distinction between comprehensiveness and selectivity seems to be a useful one, as does the following distinction between analytical and descriptive courses. The two pair of contrasting emphases furnish two different ways of characterizing any survey course.

Analytical courses. An analytical survey course is one that emphasizes relationships. These relationships may be those that exist between the facts and the generalizations of pure science, those that exist between pure and applied science, and those that exist between science and philosophy, religion, morals, economics, politics and other aspects of human life. Comprehensive and selective courses may be analytical, but are not necessarily so. The analytical course often contains considerable mathematics, since the important pure science relationships, particularly of course in the physical sciences, are usually expressed in mathematical form. The Chicago general courses are analytical, as is the physics-astronomy course at Ohio State, and the new natural science course at Columbia. The analytical course tends to be difficult for students. Several teachers of survey courses have told me that the Chicago syllabi are too difficult for their students. This, I believe, is partly due to the analytical quality of these courses, though also partly to the wide extent of subject matter they cover.

Descriptive courses. The descriptive course is one that presents information without much attempt to show relationships. The comprehensive course which covers a great deal of ground in a

[3] Public School Pub. Co., Bloomington, Ill., 1931.

small amount of time tends to be descriptive rather than analytical. Selective courses tend to be analytical, but some of them are descriptive. All courses are to some extent a mixture of both types, but the amount and the quality of the analysis justifies us in calling some courses analytical and others descriptive.

Teaching of Survey Courses

There seems to be no accepted pattern for teaching a survey course. Usually lectures, demonstrations, and discussion groups are used. A few courses are taught entirely by lectures, and a few others entirely in small conference groups. In nearly all cases, each student has one teacher with whom he is in close contact for the duration of the course, no matter how many other teachers may come in for short periods of time. Opinion among teachers of survey courses is divided on the question of individual *versus* multiple responsibility for the teaching of the course. Most comprehensive courses are taught by several specialists from different fields, but some are taught by one teacher. Most selective courses are taught by a single teacher.

Teachers of survey courses are practically unanimous in their desire to meet the students' need for concrete experience by the use of something besides books and lectures. A fourth or a third of the physical and biological courses require laboratory work, though it must be said that the problem of a satisfactory use of the laboratory in connection with a survey course has not been solved. Demonstrations arranged so that a student can come into the laboratory and get a close, detailed view of important materials and processes are used in the biological science courses at Chicago and Minnesota. At Ohio State there is a laboratory open to students who volunteer to come in and work on projects in which they are especially interested. Museums are used in connection with several courses, notably the physics museum at the University of Chicago.[4] Large collections of slides are being made and used, such, for example, as that of Professor Bawden at the College of the Pacific. Moving pictures are popular, those prepared for the Chicago courses being widely used.

[4] For details, see H. B. Lemon, Am. Phys. Teacher **2**, 10 (1934).

Advantages and Disadvantages of Survey Courses

Out of the situation in the second decade of this century, which saw specialized knowledge increasing so greatly in amount that men were being forced to confine their expert knowledge to small areas of science, while at the same time several hundred thousand new students were coming to college with no aptitude or desire for a life of scholarship, grew a demand for a kind of amateur education in the broad fields of knowledge that would be sufficient for the education of many students and would supplement for the scholar his specialized knowledge in a small field. One of the ways of meeting this situation, a way which has been followed by a number of colleges, is to develop a planned curriculum for the greater part of the first two college years. This planned curriculum contains a balanced intellectual diet which is judged to be wholesome and adequate for the students in attendance at a particular college. The natural science survey course often appears as part of such a planned curriculum. It is said to be superior to the specialized science course designed primarily for students who will do further work in science because it does one or both of the following: 1. It helps the student to secure a comprehensive knowledge of natural science. 2. It helps the student to secure a coordinated and humanized understanding of natural science. These, with the added fact that exposure to a number of different fields during his early college years may help the student to make a wise vocational choice, are the advantages claimed for the natural science survey course.

Critics from the right and from the left can point out disadvantages in survey courses. There is the conservative who emphasizes the disciplinary value of scholarly work in the patterns set by professional scientists even for students who will not become scientists, and who believes that good hard work by a student and conscientious teaching by a teacher make a valuable experience for the student no matter what the subject matter may be; he sees no reason for changing to a survey course with all of its practical difficulties. Then there is the progressive who is opposed to the planned curriculum with its prescription of a balanced intellectual diet because it does not

take sufficient account of individual differences in need and aptitude among students; he believes that the survey course, since it is set up as a body of subject matter supposedly valid for the general education of all students, is a mistake. Aside from these criticisms which spring from different educational points of view, there are certain practical difficulties which the teachers of survey courses are the first to admit. There is the difficulty of finding teachers who are well-trained or well-versed in the subject matter of more than one subject-area. In case the course is given by several specialists there is the difficulty of securing the kind of cooperation that will produce an integrated learning experience for the student. Textbooks are just beginning to appear for survey courses. We have already referred to the difficulty of getting concrete learning experiences into the course.

The oft-repeated criticism that survey courses are superficial disturbs many teachers, who believe that their particular courses are fully as analytical, and as difficult, as most elementary courses in the special sciences. There does seem to be a rather general feeling, though, that particularly in the extensive or comprehensive courses which devote but a few semester hours to a survey of the entire field of science there is a danger of superficiality.

Survey Courses in the Secondary Schools

There are some developments in secondary school science teaching that promise to affect the future of survey courses in the colleges. To explain these developments, it is necessary to describe the pattern of school science curricula today. The great majority of students who enter college have a science experience in secondary school approximately as follows. In the junior high school they pursue a general science course which is a descriptive survey. In the tenth or eleventh grade, most of them take a course in general biology which is really a survey course somewhat more analytical in character than the general science course. In the eleventh or twelfth grade the majority elect a course in physics or in chemistry.

As the secondary school physics and chemistry teachers have become more concerned about the part their courses play in general education they have begun to experiment with a physical science survey course. I have a record of 18 senior high school survey courses which were given in 1934–1935. Plans are on foot to establish a physical science course in all the high schools of Los Angeles. Pasadena is requiring all eleventh graders to take such a course. There is a possibility that the idea will spread until practically all secondary schools will offer a physical science survey course for their juniors and seniors. Such an event unquestionably would cause a change in the policy of some colleges with regard to their physical science survey courses. Several college teachers of physical science have told me that their courses could be given with satisfactory results to high school students. Some of the high school classes are now using textbooks written for college courses. There is a considerable body of opinion holding that the survey course properly belongs in the secondary school.

What the colleges now offering survey courses would do if the senior high schools generally should develop physical science courses is uncertain. Some college physical science courses are so far above secondary school level that they could continue to be given without danger of being duplicated. Others would have to be abandoned or changed. Some teachers of survey courses would drop those courses and look for some other way of making physical science contribute to the general education of college students.

WHERE neither confirmation nor refutation is possible, science is not concerned. Science acts and only acts in the domain of uncompleted experience.—*Ernst Mach*, "*Science of Mechanics*."

SCIENCE seldom renders men amiable; women never.—Beauchene.

On the Establishment of Fundamental and Derived Units, with Special Reference to Electric Units. Part I

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IN a recent article entitled *On Electric and Magnetic Units and Dimensions*,[1] I endeavored to summarize the fundamental ideas and equations involved in the so-called *absolute* systems of electric and magnetic units. Subsequent correspondence has indicated the need of a supplementary discussion of some of the questions involved in that paper. These questions relate, in general, to the methods employed in the establishment of electric and magnetic units. There is, however, no difference in principle between the methods employed for electric units and for other types of units such as mechanical units. In fact the difficulties commonly believed to be peculiar to systems of electric units occur to an equal degree in other divisions of physical science. Hence Part I of the present paper is devoted to a general discussion of the methods that have been used in the establishment of physical units, with particular emphasis on the dimensions of the resulting units. Electric units are discussed in this portion of the paper, but only in order to illustrate general principles, and to show the close parallelism between electric and other types of units.

In Part II electric and magnetic units will be discussed in more detail, with specific reference to certain criticisms of my previous paper. In that paper I had no intention nor desire to contribute anything of an original nature, and I adopted merely the general method of treatment and point of view of the great majority of authorities in the field. This fact was made clear by an explicit reference, in the case of each important statement, to one authoritative source, at least, where an identical or similar statement occurs. However, there are at least two distinctly different methods of treatment of electric and magnetic units to be found in recent literature on the subject, and both of these methods will be presented in the present paper.

There exist in the literature many detailed discussions of physical units, but such accounts usually stress the numerical relations involved, and subordinate the matter of dimensions. It is, however, the assigned dimensions that indicate most concisely the principles involved in the establishment of units. Thus two different units for the same quantity may be almost identical in magnitude, but may differ in dimensions due to the distinctly different assumptions involved in their definitions. In this paper we shall be concerned primarily with this question of definitions and resulting dimensions of units, and only incidentally with their magnitudes.

FUNDAMENTAL UNITS

Physical units are divided into two classes, *fundamental* or *primary* units, and *derived* or *secondary* units. Most of the difficulties experienced in this subject are connected with the various possible ways that have been used, or may be used, to obtain derived units. I shall start, however, with a brief discussion of fundamental units.

A fundamental unit is distinguished by the fact that it is entirely independent of all other units, in respect both to its *magnitude* and to its *dimension* or *dimensions*. It is customary to assign to each fundamental unit a specific dimension. Thus the *unit* of length is said to have the *dimension* of length. Because, however, of the arbitrary character of dimensions, as presented so ably by Bridgman,[2] the choice and number of fundamental units are arbitrary. This statement will be illustrated presently.

Let us, for the sake of argument, choose as fundamental for a mechanical system, units of length, mass and time. To these units are assigned the specific dimensions length (L), mass (M) and time (T), respectively. There are now a number of different ways in which each of these units may be chosen, but the resulting units fall in general into two distinct classes:[3] (1) The first

[1] R. T. Birge, Am. Phys. Teacher **2**, 41 (1934).

[2] P. W. Bridgman, *Dimensional Analysis*, rev. ed. (Yale Univ. Press, 1931). See also J. C. Oxtoby, *What are Physical Dimensions?* Am. Phys. Teacher **2**, 85 (1934).

[3] In the preliminary draft of this paper I adopted the analysis presented by G. Mie, *Elektrodynamik* [Vol. 11 of Wien-Harms, *Handbuch der Experimentalphysik* (1932),

class comprises units that are local in character, not exactly reproducible if destroyed, and subject to possible change with time; (2) The second class comprises units that are believed to be universal in character, indestructible, and not subject to change with time.

As examples of the first class, consider the following units of length. The adopted unit[4] may be the length of any arbitrarily chosen body. Thus the present c.g.s. standard of length is the length, at 0°C, of a particular bar of platinum-iridium deposited at the International Bureau of Weights and Measures. This so-called prototype meter is obviously local in character, and subject to possible change with time. If destroyed it could not be reproduced exactly. A better standard, from this point of view, would be the circumference of the earth, because of its more permanent character. But the earth is believed to be cooling and shrinking in size, and therefore even such a standard does not have the desired constancy with time. This is quite aside from the practical difficulty of producing a *laboratory* standard that will accurately represent some designated fraction of the earth's circumference. From 1799 to 1872 the prototype meter was, as a matter of fact, merely an auxiliary laboratory standard, designed to represent the 10^{-7} part of the earth's quadrant, so that during that period the circumference of the earth was the primary standard of length. In 1872, however, this definition was abandoned and the actual meter bar that had been constructed in 1799 was chosen as the primary standard of length.

The present c.g.s. standard of mass is, like the prototype meter, an arbitrarily chosen body known as the prototype kilogram, and is thus an example of the first class of fundamental units. On the other hand, the c.g.s. unit of mass, from 1799 to 1872, was defined as the mass of 1 cm^3 of water, at its point of maximum density. This definition makes density a primary unit, and mass a *derived* unit; hence this unit of mass belongs in the section on derived units, and is considered in more detail there. In place of the mass of the prototype kilogram, which may change with time, and is not exactly reproducible, one might choose the mass of the earth as the standard of mass. This would obviously be a poor standard, because of the difficulty in measuring it with any accuracy, in terms of laboratory standards.

Although the earth represents an unsatisfactory standard as regards length or mass, its motion has always been used in science to define the unit of time. The direct standard, in this case, is the length of the sidereal day, since this is a quantity that has no annual variation. For practical purposes, however, the *mean* solar day has been chosen, and the unit of time (the second) is defined as the 1/86,400 part of this latter standard. Such a unit of time is vastly superior to the period of some officially designated laboratory pendulum, but even the period of rotation of the earth is believed by astronomers to be slowly changing with time, as a result of tidal action. Thus all three of the present adopted primary c.g.s. units fall in class one.

The desirability of choosing standards that fall in class two is now well recognized, but unfortunately it is in general not possible to reproduce them in the laboratory with the desired accuracy. One exception is the wavelength of light, which can be measured with very great accuracy. Thus it has been found experimentally that the standard meter equals 1,553,164.24 wavelengths of red cadmium light, in "normal" air at 15°C, with a probable error of only one part in several million. If now we *define* the meter as this number of wavelengths (which corresponds to defining the wavelength as $6438.4691 \times 10^{-10}$ m), we have, in principle, adopted a certain wavelength of light as our unit of length. This unit is believed to be universal and constant in time. It is evidently reproducible, or more precisely, the laboratory standard chosen to represent some multiple of it is reproducible, if destroyed. Such a redefinition of the meter was suggested in 1923

p. 429]. His analysis, however, makes the proper classification of many units ambiguous, and the classification presented here has evolved as a result of private correspondence particularly with Professors Duane Roller and D. L. Webster.

[4] Each *unit* is represented by a *standard*, or some combination of standards, which possesses the property whose unit is being established. Thus any material object possessing length may be chosen as the *standard* of length, and the invariability of the *unit* of length will depend upon the invariability of the chosen *standard*. The invariability of the latter is necessarily a postulate, the reasonableness of which must be based on general considerations. The unit may be identical in magnitude with the standard, or may be some multiple or sub-multiple of it, but in this paper, purely for simplicity, we shall in general assume that the unit and the standard are identical.

by the International Committee on Weights and Measures, and various National laboratories are now carrying out new determinations of the length of the meter in terms of wavelengths of light, preparatory to making this change.[5]

As further examples of fundamental units falling in class two one may cite the mass of an electron, or of a proton, as the unit of mass, and the period of an atomic vibration as the unit of time. Except for purely experimental difficulties of measurement, these quantities, or some multiple of them, would constitute ideal units. If in place of length and time one should adopt length and velocity as the fundamental units of kinematics, with specific dimensions L and V respectively, the velocity of light in empty space, c, immediately suggests itself as a satisfactory unit of velocity falling in class two, Now, as will be discussed more fully in Part II, c plays a unique role among the universal constants. As a measure of the speed of a photon it is to be classified with constants like e (the charge of the electron), M_P (the mass of the proton), and h (the Planck constant). Such constants refer to properties of *elementary particles* and are suitable for use as primary units, each with a specific dimension. But as discussed in the next section, c may also play the role of a factor of proportionality in the equation of a derived unit, and as such may be assigned *zero* dimension.

Certain units are intermediate in type between class one and class two. These units usually apply to *intensive* quantities, rather than *extensive*. An extensive quantity has the property of addition, whereas an intensive quantity does not. Thus since two bodies, each of mass 1 g, have together a mass of 2 g, mass is an extensive quantity. But the density of two bodies, each of 10 $g\cdot cm^{-3}$ density, is still 10 $g\cdot cm^{-3}$, which shows that density is an intensive property. As an example of such an intermediate type of unit, consider the maximum density of water. This is a unit that does not change in time, and in one sense is not local in character. Yet it cannot be considered a universal constant in the sense that e, M_P and h are universal constants. The resistivity of mercury, at 0°C, is a further example of this intermediate type of unit. As already noted, the original definition of the metric unit of mass made mass a derived unit; the fundamental units, as chosen in 1799, were those of length, density and time, the unit of density being the maximum density of water. One further example is the international ohm, whose present definition, as shown in the next section, is equivalent to the assignment of an arbitrary numerical value to the product of the density and the resistivity of mercury, at 0°C.

[5] For an account of this work see W. E. Williams, Nature **135**, 459, 496, 917 (1935).

Derived Units

The magnitude and dimensions of a derived unit depend upon the magnitude and dimension of one or more arbitrarily chosen fundamental units. The dependence is shown by an *equation*, which is used to define the derived unit. This equation also contains a *factor of proportionality* to which, in general, one may assign an arbitrary numerical value and *also* arbitrary dimensions (*including zero*). It is this arbitrary character of the so-called factors of porportionality that is primarily responsible for the almost unlimited possibilities present in the assignment of the magnitude and dimensions of a derived unit. Most of the uncertainty and lack of agreement regarding units and dimensions seems to center at just this point, and because of that fact a rather extended treatment follows of various types of derived units and their defining equations.

(a) As a first example consider *volume*. For the purpose of defining unit volume we choose a cube, and then its volume is given directly by $(\text{length})^3$. If length is taken as a primary unit, the dimensions of the derived unit of volume are L^3, and this unit is most simply the volume of a cube of unit side. Thus the c.g.s. unit of volume is 1 cm^3. More generally one may write for volume,

$$V=kl^3. \tag{1}$$

Thus volume, in U. S. gallons, is given by

$$V=\frac{1}{231}l^3, \tag{2}$$

where l is expressed in inches. In order to *define* the gallon the constant k has been given the *arbitrary* numerical value 1/231 and *zero* dimension. There would be no possible advantage in

assigning any specific dimension to the constant, and this has never been proposed.

On the other hand, if one were so illogical as to choose an arbitrary unit of volume, that is, one not specifically related to the volume of a unit cube, then k can be interpreted as the measured ratio between these two possible units of volume, and its numerical value must be determined *experimentally*. Thus if one had adopted the gallon as the unit of volume, and the centimeter as the unit of length, during the period when the inch and yard were still primary units in this country, unrelated to the metric units,[6] then Eq. (1) would have had the form

$$V=\frac{1}{231a^3}l^3, \tag{3}$$

where V is the volume of a cube in gallons, l the length of a side in centimeters, and a the number of centimeters in one inch, as experimentally determined.

(b) The volume of a rectangular parallelopiped is given by the product of three different lengths, and it seems illogical not to use the same unit in the case of each measured length. However, the common use of "board foot" in the lumber industry, and of "acre foot" in irrigation engineering indicates the practical usefulness of such *mixed units* of volume. A very conspicuous example of the use of a mixed unit in science is furnished by the measurement of angle. Since angle is the ratio of arc to radius, the only logical scientific unit is the radian. All other units, such as revolution, degree, etc., correspond to the adoption of one unit of length for the radius, and another unit of length for the arc. Since angle is the ratio of two lengths its unit is necessarily dimensionless.[7] Thus it is possible to have more than one dimensionless unit for certain quantities by the simple artifice of using simultaneously units of different magnitudes for the same sort of primary quantity (in this case *length*) in the defining equation.

[6] The U. S. yard is now, legally, merely 3600/3937 m.

[7] On the other hand, since angle has a physical character and is not a pure number, those who believe that quantities possess *absolute* dimensions, indicative of their physical nature, are forced to extend the theory of dimensions to include the idea of direction. The most ambitious attempt of this kind is possibly that by W. W. Williams, Phil. Mag. (5) **34**, 234 (1892), who writes the dimensions of angle as XY^{-1}. I have not seen his general scheme of dimensions used by any subsequent writer.

(c) Let us consider the equation *density* = *mass*/*volume*, or

$$d=m/V. \tag{4}$$

This equation may be interpreted in three different ways. In the first place mass and length may be taken as primary quantities,[8] with volume defined by Eq. (1). Then density is a derived quantity, of dimensions ML^{-3}, and its unit, as defined by Eq. (4), is unit mass per unit volume. This corresponds to the present adopted c.g.s. system in which unit density is 1 $g\cdot cm^{-3}$, and the maximum density of water must be determined *experimentally*.[9]

In the second place, the units of length and density may be taken as primary, of dimensions L and D, respectively. Mass is then a derived unit, of dimensions L^3D, and defined by Eq. (4). This corresponds to the c.g.s. system, as it existed from 1799 to 1872. The unit of length was then, as now, the centimeter. The unit of density was the maximum density of water, and the resulting unit of mass, from Eq. (4), was the mass of unit volume of water, at its point of maximum density. The kilogram was merely a laboratory standard, constructed to represent as nearly as possible the mass of 1000 cm^3 of water but, as we now know, failing to do so by about 28 parts in a million.[9]

[8] Every equation used in science, such as Eq. (4), gives a relation between *numerical measures* of certain quantities, not between the physical quantities themselves [see, for instance, V. F. Lenzen, *The Nature of Physical Theory* (John Wiley and Sons, 1931), pp. 29–30]. Thus in Eq. (4) d is the numerical measure of density, *relative* to the adopted unit, and hence may be represented symbolically by $n[d_0]$, where n is a pure number and $[d_0]$ signifies the unit. The dimensions of d are necessarily those of the unit, and it is to the *unit*, not to the physical quantity, that one assigns a dimension or dimensions. As the title of this paper indicates, one chooses primary and derived units, but not primary and derived quantities.

This point has recently been emphasized by H. Abraham in an excellent critical paper entitled *A Propos des Unités Magnétiques* (Bull. Nat. Res. Council **93**, 8, 1933, especially pp. 10–11). However, it is still common practice to speak, as I have just done, of an equation as expressing a relation between primary and derived quantities. Such forms of expression are used repeatedly by Bridgman,[2] who nevertheless was one of the first to insist on the distinction between the numerical measure and the thing itself. In my previous paper[1] I followed Bridgman in the use of such uncritical forms of expression, which Abraham considers are very unfortunate and likely to lead to misunderstanding. With very few exceptions the mode of expression used in the present paper conforms to that preferred by Abraham.

[9] Its latest value is 0.999972±0.000001 $g\cdot cm^{-3}$; see V. Stott, Nature **124**, 622 (1929).

In the third place the units of mass and density may be taken as primary, with dimensions M and D. The unit of volume then has the dimensions MD^{-1}. If the unit of density is again the maximum density of water, the derived unit of volume is, by Eq. (4), the volume of unit mass of water when at maximum density. This is the present definition of the *milliliter*,[10] provided the gram is taken as the unit of mass, or of the *liter*, if the kilogram is chosen. Hence the milliliter and the liter are derived units of volume (or so-called "capacity") that correspond to mass and density taken as primary units. They do *not* belong to the present accepted c.g.s. system, in which length, mass and time are the primary units. The liter and the milliliter are, however, used almost exclusively by chemists as units of volume.

Eq. (4) does not contain a factor of proportionality. In order once again to illustrate certain general principles, let us insert such a factor and write

$$d = k\frac{m}{V}. \tag{5}$$

It is now possible to choose arbitrarily a unit of density, regardless of the fact that units of mass and volume have already been adopted. Thus we may *define* the maximum density of water as unity, and at the same time retain the gram as the unit of mass, and the cm^3 as the unit of volume. Then k may be interpreted as a pure number which gives the ratio between unity and the maximum density of water in grams per cm^3. As experimentally determined[11] $k=1.000028 \pm 0.000001$. On the other hand, the value of k may be *defined* as 1.000028 (with no error), and the resulting maximum density of water, using Eq. (5), is then unity (± 0.000001), an *experimental* value that may at any time be changed as a result of more accurate measurements.

The insertion of the k in Eq. (5) has thus given a certain freedom not permitted by Eq. (4). It has allowed *either* the adoption of a unit of density *independent* of the adopted units of mass and volume, *or* the retention of a unit of density depending on the units of mass and volume, but with an *arbitrarily* altered magnitude (the alteration being given by the adopted value of k). Both of these changes concern only the *magnitude* of the unit of density. The insertion of k gives, however, a similar increased freedom with regard to dimensions. Thus if it is desired to retain for the unit of density the dimensions ML^{-3}, one merely assigns to k zero dimension and interprets k as the ratio of two units of density, *each* of dimensions ML^{-3}. But one may also assign to the unit of density the specific dimension D. Then the resulting dimensions of k are DL^3M^{-1}. In other words density has now been chosen as an additional *primary* unit, and this is not an unnatural procedure in the case just mentioned where an *arbitrary* magnitude has been adopted for this unit. It is important to note, however, that the freedom to assign an arbitrary magnitude to a unit and the freedom to assign dimensions are entirely independent. It is customary to assign to the unit of density, even in Eq. (5), the dimensions ML^{-3}, and this custom seems to have resulted from the notion that these dimensions in some way give us more information about the "physical nature" of density than the specific dimension D would do. But as pointed out in footnote 8, dimensions are assigned to *units*, not to the physical quantities themselves, and Bridgman's theory of dimensions stresses the fact that the dimensions of a unit give us no information about the intrinsic nature of the physical quantity of which it is the unit.

(d) A rather detailed treatment has been given of Eqs. (4) and (5), since they typify the principles under discussion. In the remaining illustrations the general principles are quite similar and therefore need not be repeated in detail. The next equation to be considered is *velocity = length/time*, or

$$v = l/t. \tag{6}$$

Here, as in Eq. (4), any two of the three units involved can be taken as fundamental. The c.g.s. system takes the units of length and time, with velocity as a derived unit (1 $cm \cdot sec.^{-1}$). Let us, however, use Eq. (6) to *define a unit of time*, with any unit of length, such as the centimeter, as a primary unit, of dimension L, and any

[10] Sometimes denoted by *cc*. See reference 9.

[11] It is important to note that although $1/k = 0.999972$, this is now considered a *pure number* giving the ratio of two units (just like the 3 in *yards = feet/3*), whereas in Eq. (4) this number expresses the measure of a density with dimensions ML^{-3}.

convenient velocity (speed), such as the mean speed of the earth in its orbit, as a *primary* unit of velocity, of dimension V. The derived unit of time thus defined by Eq. (6) has the dimensions LV^{-1}.

Now an entirely unique velocity is that of light in empty space, c. This is called a universal constant and as succeeding illustrations will show, any universal constant *connected with the properties of empty space*, such as c, G, ϵ_0 and μ_0, may be employed, for the sake of defining a unit, like a mere factor of proportionality to which arbitrary magnitude and dimension (including *zero* dimension) may be assigned. In the theory of relativity it is desirable to call c unity and dimensionless. This defines the unit of time as the time required for light to travel the unit of length, and gives time and length the same dimension. In other words, in the equation $t=(1/c)l$, the $1/c$ is to be considered a mere *factor of proportionality*, just like the G in Eq. (9) ahead, and the a in Eq. (10), and like them it may be assigned *zero* dimension as the basis of a certain definite system of units. But in problems of science not directly concerned with relativity, such a *reduction* in the number of primary units is likely to prove more a hindrance than a help, and hence there is at the moment little advocacy of it.

(e) As a fifth illustration let us consider possible units of *force*. If force is considered as defined by Newton's second law of motion, the unit of force is necessarily a derived unit and in its simplest form is the force required to give unit acceleration to unit mass.[12] In the c.g.s. system this unit is called the dyne and has dimensions MLT^{-2}. More generally the resulting derived unit of force is to be obtained from the equation

$$F=kma. \tag{7}$$

The dyne then corresponds to $k=1$ and dimensionless. To obtain a new derived unit let k represent the dimensionless number 1/980.665. Then unit force is that force which will give to unit mass (the gram) an acceleration of 980.665 cm·sec.$^{-2}$. This is the present accepted definition of the *gram-weight*.[13] The dimensions of this unit are MLT^{-2}, just as in the case of the dyne.

One can, however, define *gram-weight* in an entirely different manner, with entirely different dimensions as the result. Let us for the moment ignore Newton's second law, and define the unit of force as the force (of gravity) acting on unit mass, when placed at a specified point on the earth's surface. The magnitude of this unit can be recorded in terms of the extension of a spring balance, on which unit mass is hung. Since the magnitude of this new derived unit of force depends solely on the adopted unit of mass, it has merely the dimension M, in place of MLT^{-2}. One can now discover, experimentally, that force applied to mass produces acceleration. When the defined unit of force is applied to unit mass, it is found that an acceleration of g_0 cm·sec.$^{-2}$ is produced, where g_0 is the *experimentally* measured acceleration of gravity at the point on the earth's surface specified in the definition. Newton's second law, in terms of the new unit of force, accordingly takes the form

$$F=\frac{1}{g_0}ma=m(a/g_0). \tag{8}$$

In this equation g_0 is, as just noted, an experimentally determined acceleration, with a unit of 1 cm·sec.$^{-2}$, of dimensions LT^{-2}. The unit of a has the same dimensions. Hence, in Eq. (8) a/g_0 is a pure number and the dimensions of the unit of F are merely those of the adopted unit of mass, in agreement with our original conclusion. If g_0 turns out by chance to be $980.665 \pm r$, where r is the probable error of measurement, the magnitude of this new "gram-weight" is the same as the first, except for possible errors of measurement. But the meanings of the two are entirely different. The pure number 1/980.665 used in Eq. (7) does not *necessarily* have anything to do with the acceleration of gravity, although the name "gram-weight" obviously implies such a relation. In general, Eq. (7), with k as *any* pure number, necessarily defines the unit of force as one giving to unit mass an acceleration of $1/k$ times the adopted unit of acceleration. Eq. (8), on the other hand, defines the unit of force as one giving to unit mass the acceleration of gravity at a

[12] We here neglect the relativity difference between $d(mv)/dt$ and ma.

[13] Int. Crit. Tables **1**, 42 (1926).

specified point on the earth. If $1/k$ is chosen to equal g_0, the two units are equal in *magnitude*, but are *not* equal in dimensions.

A third, and still different unit of force may be obtained from the equation

$$F=G\frac{mm'}{r^2}. \tag{9}$$

Here G is the factor of proportionality, to which an arbitrary numerical value and arbitrary dimensions can be assigned. It is also called a universal constant—the constant of gravitation. If now one wishes to preserve the derived c.g.s. unit of force, *as well as* the primary c.g.s. units of mass and length, G becomes an experimental magnitude, equal to 6.670×10^{-8} dyne·cm²·g⁻², with dimensions $M^{-1}L^3T^{-2}$. But one can equally well give to G the arbitrary value unity and *zero* dimension, and thus *define* a new unit of force, with dimensions M^2L^{-2}. This might be called the "gravitational unit of force." The dimensions and value of k in Eq. (7) are now just the reciprocal of those given previously for G.

It should be noticed that in all three Eqs. (7), (8) and (9) the c.g.s. primary units of length, mass and time have been adopted, and in each case the resulting unit of force is a derived unit. Yet each of the three units of force has different dimensions. This illustrates the arbitrary character of the dimensions of a derived unit, even after assuming a given set of primary units, It is, of course, also possible to make force one of the primary units, and this has often been advocated. If length and time are also assumed as primary units, each of the equations (7), (8) and (9) serves to define a unit of mass, which now becomes a derived unit, and in the case of each equation the derived dimensions of mass are different. For example, if the adopted unit of force happens to have the magnitude of the present gram-weight, and if k in Eq. (7) is unity, the resulting unit of mass equals in magnitude 980.665 g of the c.g.s. system. If the adopted unit of force equals the present pound-weight, the resulting unit of mass is about 32.2 lbs., known as the *slug*.

(f) An equation precisely similar in form to Eq. (9) occurs in electrostatics. This is the equation

$$F=a\frac{ee'}{r^2} \tag{10}$$

for the force between two charges in vacuum. Webster[14] has called a the *constant of electrostatics*. Like G, it can be considered a universal constant, and like G it can *also* be considered a mere factor of proportionality to which can be assigned unit value and *zero* dimension. If this is done one obtains the *absolute e.s. system of units*. There is, however, an historical distinction between Eqs. (9) and (10) that apparently accounts for the fact that a and G are not ordinarily accorded the same treatment. When Eq. (9) was formulated, units of force, mass and length were already in common use. It was accordingly natural to use Eq. (9) to *define* the value and dimensions of G, and this is still done in the modern c.g.s. system. But when Eq. (10) was formulated, no unit of charge had been adopted, and the equation therefore furnished a convenient means of defining such a unit, by giving a an arbitrary value and dimensions. If, however, one adopts an arbitrary (primary) unit of charge, *or* if a unit such as the *absolute e.m. unit* is *derived* from other relations, then Eq. (10) serves to *define* the numerical value and dimensions of a. The result is c^2, with dimensions L^2T^{-2}, in case the absolute e.m. unit of charge is used. The reciprocal of a is often called the "dielectric constant of vacuum," and the origin and desirability of such a designation will be considered in Part II of this paper.

(g) As a final illustration of derived units consider the international ohm. This is defined as the resistance of a column of mercury at 0°C, of uniform cross section, 106.3 cm long, and 14.4521 grams mass. It is desirable to replace this definition by a defining equation, and for this purpose we write the known experimental relation

$$R=\rho l/A, \tag{11}$$

where R is the resistance of a uniform column l cm in length and A cm² in cross section; ρ is merely the factor of proportionality and is called the resistivity. Since $l\cdot A=V$, the volume of the column, and $d=m/V$, as in Eq. (4), one can rewrite Eq. (11) as

$$R=\rho l^2d/m, \tag{12}$$

[14] D. L. Webster, Am. Phys. Teacher **2**, 149 (1934).

where now R is the resistance of a uniform column l cm long, of mass m, and density d. In order that R may be in international ohms it is necessary that for mercury at 0°C, $R=1$ when $l=106.3$ cm and $m=14.4521$ g. Hence

$$\rho d = Rm/l^2 = 1\times 14.4521/(106.3)^2 = (1.27898\cdots)\times 10^{-3} \quad (13)$$

and

$$R=(1.27898\cdots)\times 10^{-3} l^2/m. \quad (14)$$

Eq. (14) thus gives the resistance R, in international ohms, of a uniform column of mercury, at 0°C, of measured length l and mass m. One is now able to measure an unknown resistance, in international ohms, by adjusting a column of mercury until its resistance equals that of the unknown, and then measuring its length and mass. Thus the international ohm can be said to be *defined* by Eq. (12), when ρd is arbitrarily put equal to $(1.27898\cdots)\times 10^{-3}$. To get the actual value of ρ we must know the value of d. The best experimental value is [15] 13.5951 $\text{g}\cdot\text{cm}^{-3}$. With this value ρ becomes[16] 0.9407668×10^{-4} int. ohm·cm. But the value of ρ has nothing to do with the definition of the present accepted international ohm, contrary to the statement of Mie.[3]

Thus far nothing has been said about the dimensions of the units of R and ρ. Even if one assumes the c.g.s. units of l, d, and m, Eq. (12) still leaves the dimensions of R and ρ indeterminate. In the Giorgi system of electric units the international ohm is a primary unit, of specific dimension Ω. Hence the unit of ρ has the dimensions $\Omega\cdot\text{L}$, and is called the ohm-centimeter. If the international ohm is considered merely a laboratory standard representing the *absolute* ohm, which in turn is merely a name for 10^9 absolute e.m. units of resistance, then the dimensions of the international ohm are those of the absolute ohm, namely LT^{-1}, and the dimensions of the unit of ρ are L^2T^{-1}. Thus Eq. (14) defines the magnitude of the international ohm but not its dimensions, so long as the dimensions of the factor of proportionality $(1.278\cdots)\times 10^{-3}$ are left unspecified.

[15] R. T. Birge, Rev. Mod. Phys. **1**, 1 (1929).
[16] The original Siemens unit of resistance was designed to make $\rho=1\times 10^{-4}$.

The last two illustrations show that the arbitrary magnitude and dimensions of derived electric units are due to the arbitrary character of the factor of proportionality that occurs in the defining equation. But the preceding illustrations have shown that a similar factor of proportionality occurs, or may be inserted, in the defining equations of all types of derived units, and leads to an equal arbitrariness in the magnitude and dimensions of the unit. Furthermore every electric and magnetic quantity can be put into some one or more equations of the type of (10) and (11), which contain quantities whose units have already been defined in the c.g.s. mechanical system. Hence by assigning to the factor of proportionality no *new* primary dimension—in particular by assigning *zero* dimension—any electric or magnetic unit can be made a *derived* unit whose dimensions include *only* those of the c.g.s. mechanical system. The resulting system of units so derived is called an *absolute* electric or magnetic system. The factors of proportionality are sometimes called *universal constants*, but they deserve that name no more and no less than the factor in any equation that defines a mechanical unit.

The important fact is that, after one has chosen a limited number of *primary* units, each with an assigned dimension, the magnitude and dimensions of the units of all other quantities can be made to depend upon the magnitude and dimensions of the primary units. The chosen primary units may or may not include an electric or magnetic unit. The c.g.s. mechanical system of units is usually called an absolute system, and hence an electric or magnetic system that includes no new primary units is called an absolute electric or magnetic system. Controversies in this field arise primarily from the innumerable possibilities in the defining of derived electric and magnetic units. The illustrations given here have been chosen to show that these difficulties are by no means confined to such units.

I am indebted to many persons for suggestions in regard to the material of Part I of this paper. I am especially indebted to Professor V. F. Lenzen for many helpful discussions.

Applied Physics in the Search for Oil

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FOR hundreds of years, men have used divining rods or other metaphysical or psychic methods to try to find what is below the surface of the earth beyond the things which can be inferred from the visible surface. In recent years and particularly since about 1924, truly scientific means of "divining" have been developed to the stage where they are useful and economically important in the search for minerals and especially for oil.

Geophysical prospecting as an aid to locating oil is not a conspicuous activity of the oil industry. Operations are usually in the back country and out-of-the-way places and are more or less hidden, often intentionally; perhaps only the oil company scouts will know just where the geophysicists are at work. The total activity of technical oil seekers is very great, however, and is of tremendous importance to the oil industry. It is the purpose of this paper to outline the reasons for all this activity, the physical principles on which it depends and the nature of the field operations which are going on so inconspicuously every day.

Present day applied geophysics has its background in some of the fundamentals of oil geology. The accumulation of oil in an underground "pool" depends, nearly always, on the existence of geological "structure." A "structure" is any deformation of the rocks of the earth's crust. An oil "structure" is one in which the rocks are deformed in such a way as to form a trap for oil which migrates through porous rocks. The pores of most rocks ordinarily are full of water. If oil is formed in or is squeezed into such porous rocks, it tends to rise, being lighter than the water, and so migrates upward. If its vertical movement is stopped by an impervious layer above the porous rock, it will tend to migrate laterally, provided that the impervious rock has a little slope or "dip." The oil moves "up dip" until it is stopped at a structure that forms an anticline[1] or dome of some kind. It gradually accumulates at such a place by displacing the water in the porous rock and thus makes an oil "pool." If the general nature of the rock series is such that oil is likely to be present, the finding of a structure may mean the finding of an oil field.

Many structures give some visible evidence of their presence at the surface and can be found by geological mapping. Many others are buried under deposits laid down after the earth movements responsible for the structure were completed so that there is absolutely no visible surface indication of them. However, these invisible structures may make just as good oil fields as the more evident ones, and most of the latter have now been found. It is the success in finding invisible structures by physical measurements at the surface that has led to the present-day activity in geophysical prospecting.

Any conceivable quantity that could be measured at the surface and that would indicate the presence of geologic structure under a cover of from hundreds to thousands of feet of overlying rock obviously might be made the basis of a method of prospecting. Many methods have been suggested and tried, including many that are purely psychic, but practically all the successful geophysical activity in the search for oil is confined to gravitational, magnetic and seismic methods. Electrical methods have had comparatively little use in oil prospecting but are employed extensively in prospecting for metals.

The gravitational and magnetic methods depend on the detection of irregularities in the gravitational or magnetic field at the surface, caused by mass or magnetic irregularities below the surface, and the correlation of these irregularities with structure. The seismic method depends on the fact that elastic waves are refracted and reflected back to the surface under certain conditions and that measurements of the time of travel of such waves can be interpreted to indicate the nature and position of the beds through which the waves have passed.

[1] An *anticline* is an upward bending of rock strata; the rocks slope down or "dip" from the anticlinal axis. A *syncline* is a downward bending, with dips toward the synclinal axis.

Vocational Aspects

Employment in geophysical prospecting can be divided roughly into three classes: laboratory development, including design and testing of equipment; field operation of equipment; interpretation of field measurements. Often a person may be employed in different classes of work at different times or even at the same time.

1. *Laboratory development of equipment* may concern any of the geophysical methods. Some equipment is fairly well standardized and is usually purchased, but much is not. Standard commercial equipment may have to be modified for special conditions or improved operation. For instance, torsion balances and magnetometers are usually obtained from instrument makers, such as the Askania Werke of Berlin, whose instruments are the most commonly used in this country. On the other hand, seismograph equipment is of many types, and to a certain extent, each operating company designs and builds its own. Recently, however, commercially built seismograph equipment has been made available by instrument companies such as Cambridge and Askania and is used to a limited extent. In the newer lines of development, such as the pendulum and gravimeter, the apparatus is still more or less in the experimental stage and is being made and tested by the operating companies. The men engaged in this development are of course mainly physicists or engineers, many with graduate work and doctor's degrees.

2. *Field operation of equipment* involves more than routine manipulation and taking of readings. Difficulties of weather and terrain must be met; equipment may have to be taken to inaccessible places or across streams without bridges. The leader of a field troop must be technically competent to handle his equipment but must be much more. He is business and personnel manager for his party, and must see that his trucks and equipment are kept in good condition. Perhaps half of the men of the average field crew have had at least some college training in physics, engineering or geology. The others are laborers, truck drivers, and technical assistants.

3. *Interpretation of field measurements* is usually made by a physicist who has learned some geology or a geologist who has learned something of the physical background of geophysical methods. Physics and geology do not mix easily. The physicist must learn to appreciate that geology is not an exact science, that the physical properties of the materials with which he is dealing are not accurately known and that geophysical data often can be satisfied by many solutions. He must depend upon the geologist or on his own geological experience to indicate the most probable answers to his problems. The geophysical interpreter frequently must give the best answer he can, based on very inadequate data, for geophysical exploration is very expensive. Also the interpreter must always remember that his results, if they are to be made most valuable, must be easily comprehensible to the less technically trained men who make use of them.

During the last half of the year 1934, the numbers of parties engaged in geophysical prospecting for oil in the United States were approximately as follows: 113 seismograph (nearly all reflection parties), 7 magnetometer, 41 torsion balance, 3 pendulum, 2 gravimeter. This activity is divided between operations made directly by oil companies and those of geophysical exploration companies who contract their services to oil companies. It employs in the field, in development of equipment, and in interpretation of results, a total of about 3000 men, of whom about half are college-graduate physicists, engineers and geologists. The total expenditure by the oil industry for this work is of the order of $10,000,000 per year.

The question is often asked, "Why all this activity in hunting for new oil when the oil industry is having so much trouble because of overproduction?" The answer is the future supply. It is estimated that the known oil resources in this country will supply the present rate of production for 10 or 15 years. In the last four years the new oil found in the United States has been much less than the oil consumed. The search will go on until large new sources are located. Deeper drilling has revealed possibilities of very deep structures (oil is produced from a depth of nearly 10,000 ft. and the deepest well is 12,786 ft.) and the deeper the structure the less its chance of surface expression. Also, the untested structures that are visible from the surface are becoming fewer. Both these factors greatly increase the importance of geophysics in the search for oil. Geophysics has proved its worth and made its place and is certain to have a very active and important part in this search in the years to come.

Gravity Prospecting

The usefulness of gravity measurements for geophysical prospecting depends upon the fact that the irregularities in density caused by geologic structure often produce measurable irregularities in the gravitational field at the surface. A local mass excess, caused by the geological uplift of relatively heavy rocks, will distort the field by the addition of small components, indicated by the short arrows in Fig. 1. The effect of the local excess mass is to increase the field

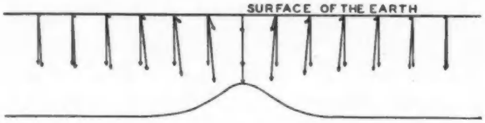

FIG. 1. Gravity vectors over a mass anomaly.

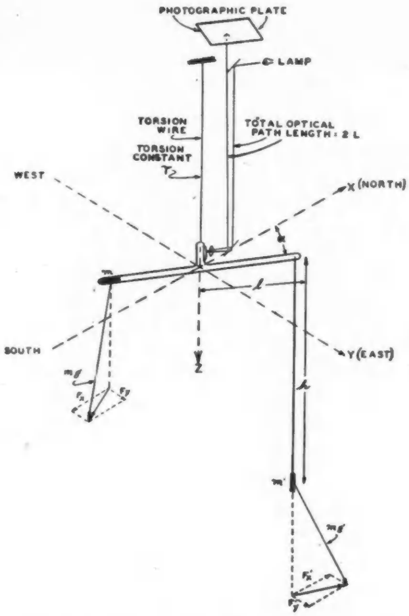

FIG. 2. Schematic diagram of torsion balance.

strength slightly and, except directly above the center of the mass excess, to make its direction deviate slightly toward the excess mass. As a result of this deviation, the "level surface"[2] is warped slightly upward over the mass excess. If the geological uplift causes a local mass deficiency, the sign of the effects is changed and there is a decrease of "gravity,"[3] a deviation of the vertical away from the mass deficiency, and a downward warping of the level surfaces. The total "gravity anomaly" caused by a structure may be as small as 0.001 gal, which is only 1 part in 10^6 of the normal gravity.

Gravity anomalies are determined either by measuring the gravity differences *directly* with a pendulum or a static gravity-meter (gravimeter) or by measuring the distortion of the vertical and warping of the level surfaces by a torsion balance.

The torsion balance

The torsion balance is the oldest and still the most common instrument used for gravity prospecting. It was invented about 1880 by a Hungarian physicist, Baron Eötvös, who was interested in determining the shape of the earth and in proving the exact proportionality of weight to mass. In principle, the instrument comprises two weights, suspended by a very fine torsion fiber and displaced both horizontally and vertically from their common center of gravity. In the form used by Eötvös and still most common (Fig. 2) it consists of a light, horizontal beam, suspended from a torsion wire, the beam having a mass m at one end and an equal mass m' suspended by a second wire from the other end. Torsional deflections of the beam are indicated by a mirror, and a scale or photographic plate.

Since, in general, the direction of the gravitational fields at the two weights are not quite parallel there are very small horizontal force components which produce a torque on the beam (Fig. 2). The magnitudes of these force components depend upon the space rate of change of the horizontal components of the gravitational field strength and on the physical dimensions of the moving system. Since the field strength in any direction is the derivative of the gravitational force function,* its space rate of change is a second derivative of the gravitational force function. Thus the torque, T, is proportional to combinations of certain second derivatives of the force function, U, and is, in fact, given by

$$T = mhl(U_{yz} \cos \alpha - U_{xz} \sin \alpha) + (K/2)(U_{yy} - U_{xx}) \sin 2\alpha + K U_{xy} \cos 2\alpha. \quad (1)$$

[2] The term "level surface" or "level" refers to the gravitational equipotential surface; for example, the surface of a free liquid.

[3] In geophysical literature, the term "gravity" means the gravitational field strength, or acceleration of gravity. The common unit is the *gal*, named for Galileo; 1 gal = 1 cm·sec.$^{-2}$.

* The *force function* is commonly called the "potential" in torsion balance literature; it is the negative of the ordinary, classical gravitational potential. The convention of the force as the positive derivative of this "potential" seems to have been introduced into torsion balance literature by Eötvös himself, for it appears in his original paper in 1896.

The deflection of the spot of light on the scale or photographic plate is given by

$$S-S_0=2LT/\tau. \qquad (2)$$

In these equations, L, τ, m, h, and l are constants of the moving system, as indicated in Fig. 2; K is the moment of inertia of the suspended system, $\cong ml^2$; $U_{xz}=\partial^2U/\partial x\partial z$, $U_{yz}=\partial^2U/\partial y\partial z$, etc.; α is the azimuth angle of the beam with respect to the x axis (x=north, y=east, z=vertically downward at the center of gravity of the moving system). In the instruments made by Eötvös and in many modern commercial balances, the constants of the moving system are approximately: $l=20$ cm, $h=60$ cm, $m=m'=30$ g, $K=25{,}000$ g·cm², $\tau=0.5$ dyne·cm·radian⁻¹, $L=75$ cm. The torsion period of such a suspended system is about 25 min.

Eq. (1) contains the unknown quantities U_{xz}, U_{yz}, $2U_{xy}$ and $U_{yy}-U_{xx}$; the quantity $U_{yy}-U_{xx}$ is usually called U_Δ in torsion balance literature. The zero position, S_0, from which the deflection is measured, also is unknown. Thus there are five quantities to be determined. Different simultaneous equations containing them are obtained by taking observations for different azimuth angles, α. For a single beam, observations in five azimuths are required. However, in practice the balance is always made with two suspended systems at 180° with each other. This adds one more unknown, the S_0 for the second beam. But each azimuth of the instrument gives two azimuths of the beams, differing by 180°; thus at least three readings of each of the two beams are required to give six linear equations from which the four unknown second derivatives and the two unknown zero positions can be determined.

The quantity U_{xz} is the x-component of the horizontal gradient of gravity (for $g=\partial U/\partial z$ and $\partial g/\partial x=\partial^2U/\partial x\partial z=U_{xz}$) and U_{yz} is the y-component. The "gradient"[4] is the vector sum of these two, and is obtained by making the plot shown in Fig. 3. Gradients point toward a mass excess or away from a mass deficiency. Gravity differences can be calculated from gradients just as height differences can be calculated from slopes. The unit of measurement of gradients is the *Eötvös unit,* abbreviated $E°$; 1 $E°=10^{-9}$ cm·sec.⁻² per horizontal cm $=10^{-9}$ sec.⁻². Gradients due to geologic structure are commonly from 2 to 20 $E°$, but may be as large as 150 $E°$. Commercial torsion balances measure gradients to about 1 $E°$.

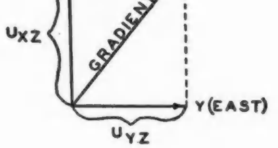

FIG. 3. Components of gradient vector.

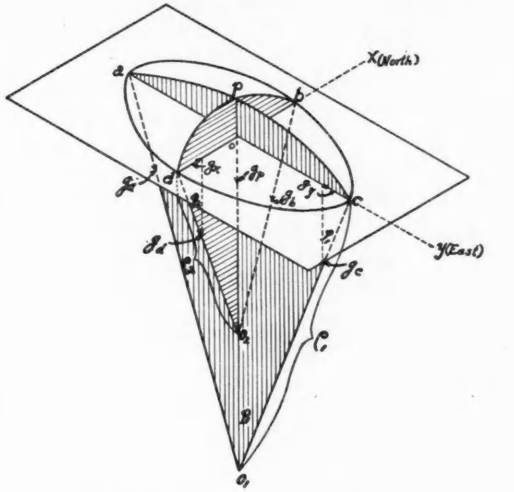

FIG. 4. Diagram of curved surfaces.

The relation of the torsion balance quantities to the curved level surface and the "differential curvature" are shown by Fig. 4. Let a horizontal plane, perpendicular to the vertical at P, intersect the curved level surface in the ellipse $abcd$. The direction of the vertical at each of the points P, a, b, c, d is indicated by the arrows g_p, g_a, g_b, g_c, g_d. If the planes $aPCO_1$ and $dPbO_2$ are the principal planes, the maximum and minimum radii of curvature of the level surface are ρ_1 and ρ_2, respectively.[5] Let us consider all the

[4] In torsion balance literature "gradient" always means the maximum horizontal rate of change of the vertical component of gravity.

[5] From a theorem of differential geometry, two planes can be passed through any point on a curved surface, in one of which the radius of curvature is a maximum and in the other of which it is a minimum, and these two planes are mutually perpendicular. These are the "principal planes" indicated in Fig. 4.

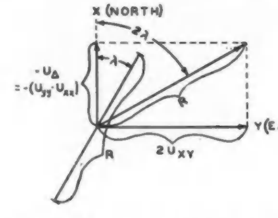

FIG. 5. Components of curvature.

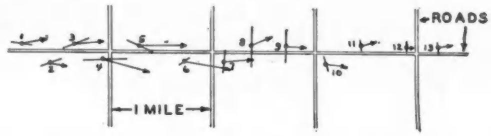

FIG. 6. Map showing torsion balance stations spaced about 1/4 mi. apart.

elements in Fig. 4 as small differentials. Then the small horizontal gravity component, g_y, is the rate of change of the horizontal force in the y-direction (U_{yy}) times the horizontal distance OC. But this same horizontal force is the projection of the slightly inclined total gravity g_c, so that $g_y = g_c \sin \varphi_1 = gOC/\rho_1$. Hence $U_{yy} = g/\rho_1$. Similarly $U_{xx} = g/\rho_2$. Then, for this special case of the principal planes in the x and y axes,

$$U_{yy} - U_{xx} = g(1/\rho_1 - 1/\rho_2) \equiv R.$$

For this special case the other curvature component, U_{xy}, is zero. The quantity $g(1/\rho_1 - 1/\rho_2)$ is the "differential curvature" of torsion balance literature and is simply the acceleration of gravity times the difference in the curvature of the level surface in the two principal planes. For a spherical level surface $\rho_1 = \rho_2$ and the differential curvature is zero.

For the general case in which the principal planes are not in the coordinate axes, it can be shown that $g(1/\rho_1 - 1/\rho_2) = [(U_{yy} - U_{xx})^2 + (2U_{xy})^2]^{\frac{1}{2}}$ and that the azimuth, λ, of the plane in which the curvature is algebraically minimum is given by $\tan(2\lambda) = -(U_{yy} - U_{xx})/2U_{xy}$.

The symbol conventionally used to represent the differential curvature is a line, the length of which is proportional to R and the direction of which is the direction of the principal plane in which the curvature is an algebraic minimum. The geometrical relations between the quantities U_Δ and U_{xy} and the curvature symbol are shown in Fig. 5. The curvature quantity has the dimensions g/ρ, or acceleration divided by a length; since this is the same as for the gradient, it also is measured in Eötvös units. Commercial torsion balances usually measure curvatures to about 1E°, and their magnitudes have about the same range in nature as do the gradients.

The results of torsion balance measurements are mapped by showing the points occupied by the instrument in the field and plotting the gradient vector and curvature symbol for the respective stations at these points. A common scale for plotting is one millimeter per Eötvös unit for both gradient and curvatures. Thus a traverse of torsion balance stations along a road might be mapped as in Fig. 6.

Different types of geologic anomalies or structures have characteristic torsion balance indications by which they often can be recognized. For instance, an anticline[1] of heavy rocks is a local mass excess, over which there is a gravity excess; the gradients point toward the anticlinal axis. The level surface is slightly arched upward over the anticline; the radius of curvature is a maximum (i.e., the curvature is a minimum) along the anticlinal axis, so the curvatures tend to lie parallel to the axis. Over a syncline of relatively heavy rocks, or an anticline of light rocks, there is a mass deficiency and the gradients point away from the synclinal axis. The radius of curvature of the level surface is negative in the plane perpendicular to the synclinal axis and therefore the curvature is algebraically minimum in that direction; thus the curvatures tend to lie perpendicular to a syncline. Over a fault there is an increase of gravity toward its upthrow (heavy) side, with the maximum rate of increase directly over the fault; hence the gradients are perpendicular to the fault and toward its upthrow side, with the maximum gradient over the fault. The level surface is concave on the downthrow side and convex on the upthrow side, so the curvatures are synclinal (perpendicular to the fault) on the downthrow side and anticlinal on the upthrow side. The gradients and curvatures of Fig. 6 are drawn as they might appear over a fault about at station No. 6 but with some erratic disturbances. A fault indication as clear as that shown in Fig. 6 would be considered good in ordinary field practice.

Instruments and field practice. The main body of the torsion balance instrument consists of three metal housings one inside of the other but thermally insulated, the moving system being inside the inner housing. This construction is necessary to minimize disturbances from convection currents. The outer housing is mounted rotatably on a pedestal which contains a spring driving motor to rotate the instrument into different azimuths.

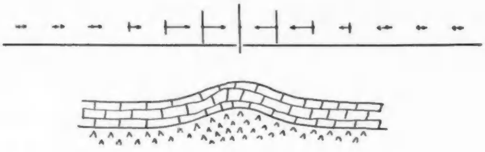

FIG. 7. Torsion balance stations over an anticline.

The instrument is protected by a portable hut which may be made of thermally insulating material or the instrument itself may be covered with an insulating covering. Modern balances are entirely automatic in operation. The spring motor and an auxiliary timing clock in the base serve to rotate the instrument into successive azimuths, allow it to wait in each azimuth the proper time for the beams to come to rest, and control the electric lights for recording the deflections of the beams.

Because the torsion period of the instrument is so long it takes 40–60 min. to come to rest after it is disturbed. Since readings in at least three azimuths are required and one to three checks are desirable, it is the usual practice to leave the instrument at least five hours at each station site.

Since the balance is strongly affected by any mass irregularities near the instrument, it is necessary to make a special survey at each station site to permit the calculation of these terrain influences. The uncertainties of these calculations or the amount of work required to make them are so large if the topography is rough that the use of the torsion balance is practically limited to areas of flat or only moderately irregular terrain. A second correction is the "normal effect" due to the fact that the earth is not a perfect sphere and is rotating. Thus, there is a normal northward gradient (in the northern hemisphere) and a normal north-south differential curvature because the radius of curvature is greater in the meridian than perpendicular to the meridian. These effects are easily calculated as they depend only on the latitude. In intermediate latitudes they amount to from 4 to 8E° in both gradient and curvature.

A torsion balance field party often operates two or three instruments and makes 2 or 3 stations per day per instrument. The crew must select station sites, secure permits from land owners, set up, take down and move the instrument from station to station, make the necessary terrain correction and station position surveys, calculate terrain and instrument results, and map and report the results. Such a crew may contain 4 to 10 men, and may operate from 2 to 4 trucks and cars depending on the nature of the country and the number of stations made each day. The final interpretation of the data is usually made at a central office and not in the field.

The pendulum

In recent years the development of relative gravity measurements by a pendulum has reached sufficient speed and precision to be useful for prospecting. Modern field pendulum equipment, in an observation requiring about one hour, will measure gravity differences to 2–3 parts in 10^7 of total gravity. Relative gravity measurements are made by swinging sets of pendulums side by side at a base station and carefully comparing their periods, and then moving one set to a field station at a distant point and again comparing their periods by radio communication. If the pendulums themselves are perfectly constant, the difference in relative period in the two cases is caused only by the difference in gravity between the base and the field station.

Outfits for prospecting have two or three separate pendulums in the same case. These are not the old style bob-on-a-staff type but are bar-shaped, and made of invar or a similar alloy, or of fused quartz. The perfection of the knife-edge and the plane on which it rests are critically important and both are made of optically flat surfaces. The pendulums are swung in evacuated cases, sometimes with temperature control. Starting, stopping and clamping for transport are done from outside the case without disturbing the vacuum. An auxiliary apparatus serves to record the swings. Periods may be compared by a coincidence method in which a continuous record of the relative phase of the pendulums is made, or by marking a simultaneous time signal at the beginning and end of a run and determining the phase position of the base and field pendulum with respect to the time signal mark. The pendulums usually have a period of about 0.5 sec. and it requires swinging them for about one hour to make a sufficiently accurate comparison of their periods. To detect a gravity change of 2 parts in 10^7 means, for an hour's swing, that the phase of the pendulum relative to the time signal must be

determined to about 0.0003 sec. No matter how the comparison is made, the base-station pendulum is essentially a clock by which the period of the field pendulum is measured.

The distance between base and field stations is limited only by the distance over which good radio communication can be maintained and by the time of travel to the field and return to the base for frequent comparison. In practice, field stations are usually 20–30 mi. from the base but may be as much as 100 mi.

Before being useful for indicating geologic irregularities, the observed gravity differences must be corrected for three effects. These are (1) the latitude correction, because of the increase of gravity toward the poles; this corresponds to the torsion balance "normal correction" and amounts to *ca.* 0.001 gal·mi.$^{-1}$; (2) the elevation correction, because of the variation of gravity with distance from the center of the earth; it amounts to *ca.* 0.0001 gal/ft. of elevation; (3) the Bouguer correction, which takes into account the mass excess below a topographically high station or the deficiency of mass above a low station; it varies with the density of the surface rocks and is roughly one-third the magnitude of the elevation correction. Since these corrections are usually made to a precision of 0.0001 gal, they require that the latitude of stations be known to about 500 ft. and the elevation to about 1 ft. This means that a high-grade plane table and level survey must be made as an auxiliary to a pendulum survey, unless government or other surveys of sufficient precision and detail are available.

A pendulum party may operate one or more field units. The party requires several men for the equipment at the field station, base station operators and a radio operator, computers to reduce the field observations and surveyors; it may require from 25 to 40 men. A party with two field units may observe from 6 to 10 stations per day. The distribution of stations depends on the geology of the area. Where the structures cover large areas and may cause gravity anomalies of several milligals, stations may be several miles apart. Where they are more local and may cause gravity anomalies as small as 1 milligal, stations may be only a mile or two apart. If still further detail is desirable it is usually preferable to use the torsion balance or gravimeter.

Gravimeters

Static gravity measuring devices are beginning to be used for prospecting. Various physical principles have been proposed and tested for use as gravimeters but, so far, the most successful field instrument is essentially a weight suspended on a spring. Some sort of optical magnification is used to indicate the very small differences in length of the spring due to variations in the gravitational attraction on the weight. The constancy of the spring is fundamental to the success of such an instrument and extreme precautions must be taken to protect the spring from any influence that may affect its elastic properties or its length. The difficulty of constructing such an instrument may be appreciated when it is pointed out that with a spring having an elongation of 10 cm the change in length produced by a change of 0.2 milligal in gravity is about one-tenth the wavelength of yellow sodium light. It has been well stated that any gravimeter sensitive enough to be useful for prospecting is also a very sensitive thermometer, barometer, seismometer, magnetometer and level. Therefore, unless proper precautions are taken, it may be indicating changes in one or more of these other possible variables rather than gravity.

In the field, gravimeter stations are usually made in a line and relatively close together—often along a road. Setting up and reading the instrument may require only 10–15 min. Frequent checks on some fixed reference point are necessary to determine the changes in the instrument as there is always some drift. Auxiliary surveys for elevation and position must be run in much the same way as for pendulum measurements, for gravity differences determined with the gravimeter also must be corrected for height, latitude and mass effects.

Magnetic Prospecting

In magnetic prospecting, measurements are made to determine variations in the earth's magnetic field. In oil prospecting only the variation in the vertical component is measured; it is much simpler to measure than the horizontal component or the total field, and experience has shown that comparatively little is gained by measuring more than the vertical component.

Nearly all sedimentary rocks are almost nonmagnetic whereas nearly all igneous or basement rocks (granite, gabbro, etc.) are somewhat magnetic. For this reason, magnetic surveys are useful primarily for indicating the major features and

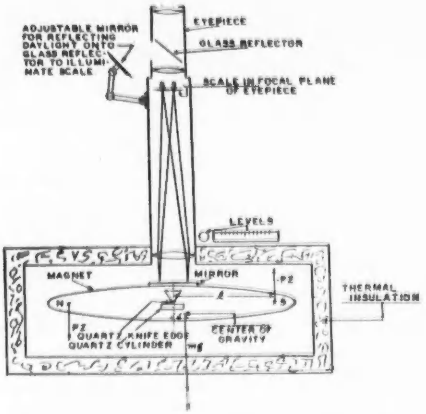

FIG. 8. Schematic diagram of magnetometer.

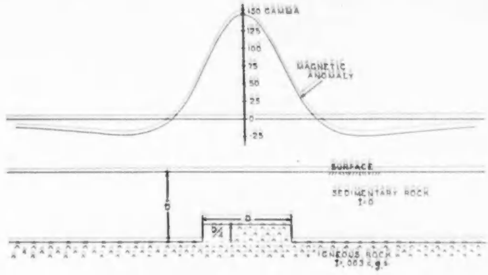

FIG. 9. Structure and magnetic anomaly.

rough depths of basement rocks. Where sedimentary structures are underlaid by pronounced basement uplift, a magnetic survey may give definite evidence of such structures. Fig. 9 shows a hypothetical structure in basement rocks and the anomaly in vertical magnetic intensity which it would produce. The curve is calculated for a uniform vertical polarization of 0.003 c.g.s. units in the basement rocks and negligible polarization in the sediments. The curve shows a central, relatively strong positive region flanked by a weak negative one; this is a general characteristic of vertical magnetic anomalies of finite forms with vertical polarization.

The vertical magnetometer is essentially a bar magnet supported on a central knife-edge and free to rotate about a horizontal axis. Since the torque of the magnet in the earth's magnetic field is almost balanced by a gravitational torque, the axis of the magnet is approximately horizontal. Consider the magnet (Fig. 8) to have poles P and $-P$ at a distance $2l$ apart. Then the torque due to the vertical component of the earth's field, Z, is $2lPZ = MZ$, where M is the moment of the magnet. This is opposed by a gravitational torque, mgd, where m is the mass of the moving system and d is the horizontal distance between the knife-edge and the center of gravity of the moving system. When $MZ = mgd$ the axis of the magnet is horizontal. Now if everything else is kept constant and there is a small change in Z, the magnet will rotate on the knife-edge. The angular position of the moving system, relative to the gravitational vertical, is indicated by a telescope having an illuminated scale in the focal plane of the eyepiece, and in the same plane, an image of the scale formed by a lens and a reflection from a mirror on the moving system. Thus, if the instrument is set up at two different points, the difference in the scale readings ($S - S_0$, Fig. 8) is a measure of the difference in the magnitude of the vertical component of the earth's field at the two points. The calibration or "scale value" is determined by reading the deflection resulting from a known magnetic field, produced by a calibrated magnet at a measured distance, or more accurately by a special Helmholtz coil which fits over the magnetometer.

A commonly used vertical field balance has two elliptical shaped magnets each with a magnetic moment of 1000–1500 c.g.s. units. The magnets are supported on a quartz knife-edge which rests on quartz cylinders. In the newer instruments the moving system is compensated for the effects of temperature on the magnetic moment of the magnets and on the relative position of the knife-edge and center of gravity. The instruments can be adjusted to have a sensitivity of 1 scale division for a change of field of 15–30 gammas[6] and can be read, in the most careful field work, to about 5 gammas. This is the order of 1 part in 10^4 of the normal vertical field strength.

Magnetometer field observations must have two corrections. The first is for the normal increase in the vertical intensity toward the earth's magnetic poles; this commonly

[6] The *gamma* is the common unit of field strength in magnetic prospecting. One gamma $= 1 \times 10^{-5}$ oersted. The normal vertical field in intermediate latitudes is *ca.* 50,000 gammas.

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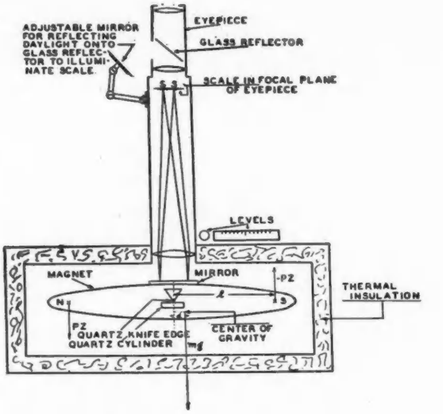

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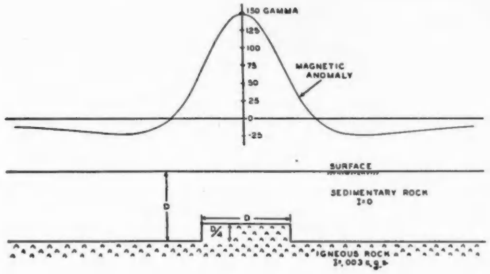

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amounts to 10–18 gamma/mi. The second correction is for diurnal variations; this may amount to 10–100 gamma/day and may be determined by a fixed instrument read at frequent intervals during the day or by returning the field instrument several times a day to the same point. Occasionally there are magnetic storms, lasting from a few hours to several days, during which the earth's field varies suddenly and erratically, with sufficient magnitude to interfere seriously with precise field work.

A magnetometer field party may consist of only one man, with an instrument and a car. The actual setting up of the instrument, orientation with respect to the magnetic meridian, leveling and reading require only about five minutes for an experienced operator. If a fixed instrument is used to determine the diurnal variation, a second operator and instrument are required but this instrument can be used with several field instruments. Sometimes the operator has an assistant who travels with him. Where stations are along roads and can be reached by a car and with stations a mile or so apart, a single instrument may make 20 to 30 stations per day.

Seismic Prospecting—Refraction Method

The refraction seismic method is based on the measurement of the time of travel of artificial compressional waves from a dynamite explosion to detectors and recorders placed at various distances from the shot point. By means of wire or radio communication from shot point to recorder, the instant of explosion is marked on the record that shows the earth's movement. Timing marks on the same record then make it possible to determine the travel time of the elastic wave from shot point to detector usually to a precision of about 0.001 sec.

The usefulness of the refraction method depends on the fact that the speed of propagation of seismic waves nearly always increases with depth. The resulting refraction causes the wave trajectory to be concave upward and thus some of the energy returns to the surface after penetrating to a depth that depends on the velocity distribution and on the distance between shot point

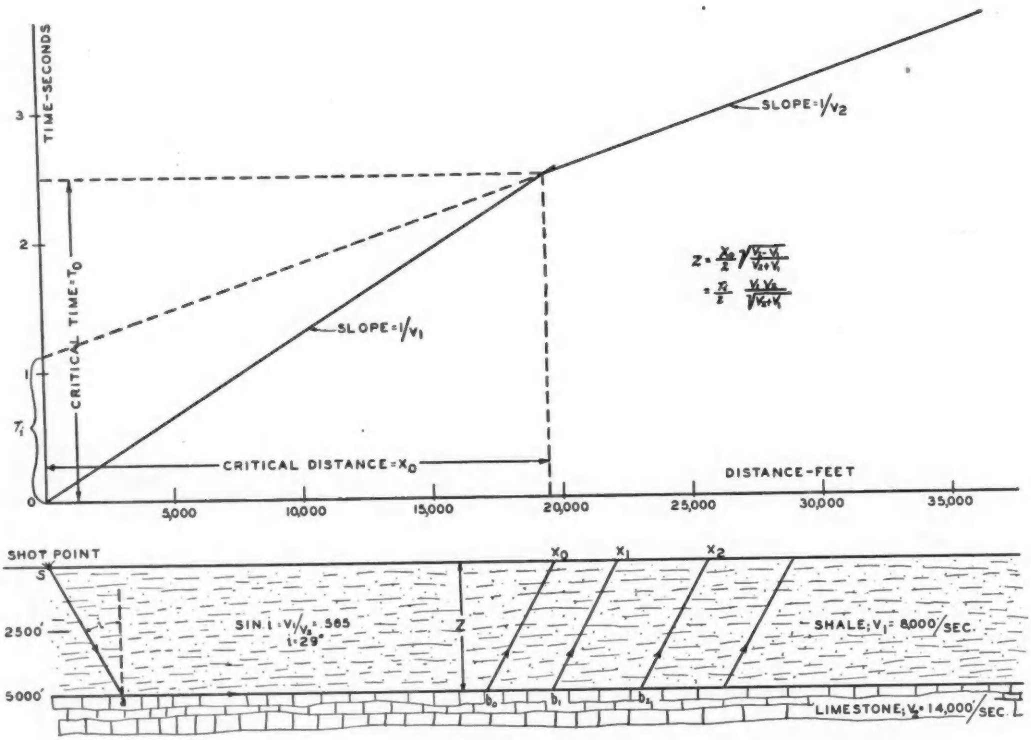


FIG. 10. Refraction path and *time-distance* curve for two layers. Formulas for depth are shown.

and detector. The nature of the curve showing the relation between travel time and shot detector distance—the *time-distance* curve—depends solely on the velocity distribution and thus gives definite information about the nature and position of the underlying rocks.

Consider first a simple case with two horizontal layers in which the speeds are v_1 and v_2, with $v_1 < v_2$ (Fig. 10). The first impulse to reach detectors close to the shot point will travel horizontally in the upper medium and will arrive in a time x/v_1; the time-distance curve has a slope $1/v_1$. Part of the energy will travel in a ray which strikes the interface at the critical angle, i, such that the refracted wave in the second medium is parallel to the interface. Some of this energy is refracted back into the upper medium so that detectors are disturbed by rays which have traveled paths such as sab_1x_1, sab_2x_2, etc., and these are minimum-time paths for waves reaching the second medium and returning to the surface. At a certain critical distance x_0, the wave that has traveled in the lower medium will reach the detector at the same time as the one that has traveled in the upper medium because the time gained while it is in the high speed medium makes up for the greater total path length. Beyond this critical distance, the time for the lower path is less; that is, the first waves to reach the detector have traveled the lower path. For these paths, the slope of the *time-distance* curve is $1/v_2$ and there is a change of slope at the critical distance x_0. Thus the *time-distance* curve itself gives the speeds in the two mediums and the depth of the interface can be calculated easily from these speeds and the critical distance. Fig. 10 has been constructed quantitatively for the constants there given.

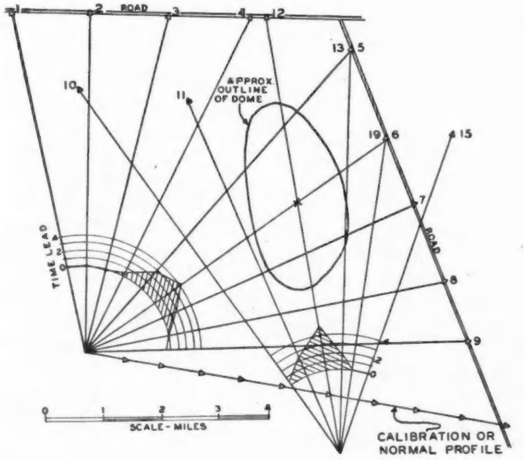


FIG. 11. Fan shooting.

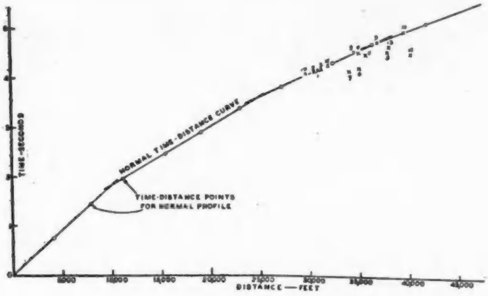


FIG. 12. *Time-distance* curves for fans in Fig. 12.

A fairly common situation is that in which there is a series of beds with successively increasing speeds. For each bed there is a discontinuity and change of slope of the *time-distance* curve (Fig. 12). The depths and thicknesses of the beds can be calculated from the slopes of the different parts of the curve and the positions of the discontinuities.

A special method of operation, called "fan shooting," is particularly useful if the object of the survey is to find local irregularities in an otherwise generally homogeneous region. It has been used successfully to locate salt domes in Texas and Louisiana. A series of shots is fired at a single point and the time determined for the seismic wave to travel to detectors placed in different directions from the shot point (Fig. 11). A "normal *time-distance* curve" for the general area is determined from a series of shot-detector distances along a line. The *time-distance* points for each detector position are then compared with this normal curve. If a point falls below the curve a "lead" is indicated (Fig. 12) which means that the seismic wave has reached a given detector in less than normal time, and therefore that there is a material for which the speed is unusually high between shot point and detector in that direction. In a territory where salt domes are expected, this may indicate a dome as the wave speed through salt is much higher than through sediments. The decrease in time, or "lead," is plotted along each ray (Fig. 11). The ray with maximum lead has come closest to passing directly through the dome. In order to locate the dome more definitely, a "cross fan" is shot with rays intersecting those of the first fan. The intersection of lines with maximum leads indicates approximately the center of the dome and the amount of "lead" together with the relative location of the rays showing leads gives an approximate outline of the dome.

Reflection Seismic Method

In the last few years the reflection method of seismic prospecting has been developed. At the present time it is the most actively applied of all the geophysical methods. It depends on the detection of seismic waves reflected from boundaries of definitely recognized rock strata or other velocity discontinuities below the surface. If the average wave speed is known, the depth of the reflecting bed can be determined, for the time of travel can be measured accurately from the detector record. From a series of such determinations the surface of the reflecting bed can be mapped.

The first essential of reflection shooting is to be able to recognize the reflection and separate it from other disturbances on the detector record. Such disturbances are caused by waves that travel a direct or nearly horizontal path from the shot point and usually reach the detectors before the reflected waves. However, if a series of detectors is placed in line with the shot point, these horizontal waves reach the detectors at different times whereas the reflected waves will arrive at all of them at nearly the same time. Then with the records of the different detectors side by side on the same photographic film or tape (Fig. 13), the reflections can be recognized if they are at all definite.

Usually from 4 to 6 detectors are set at intervals of 50–250 ft., with the first detector from 200 ft. to 1/2 mi. from the shot point. The exact arrangement or "spread" varies greatly and depends on the depth of the beds being mapped and the general character of the sub-surface material. The shot is nearly always in a drilled hole and may be from 15 ft. to as much as 200 ft. below the surface. This is necessary because there is nearly always a comparatively shallow zone of unconsolidated rock, usually called the "weathered layer," where the wave speed is much lower than in the deeper material. If the shot is not below or well within this layer it is difficult to get enough energy below it to give good reflections.

Because of the markedly different speed and its variable thickness, the depth of the "weathered layer" must be determined for each detector "spread." This can be done from the first arrival times by the application of the refraction seismograph principles outlined in a preceding section, for each detector spread can be treated as a refraction profile. Corrections are then made to the reflection time intervals to allow for the excess time taken in this lower-speed material. Corrections also must be made for the depth of the shot hole and the elevations of the detectors.

With all corrections properly made, the travel time is reduced to what it would be for an average vertical speed from the surface to the reflecting layer. This average speed can be determined directly from shots fired in wells or from reflections that can be definitely attributed to boundaries of rock strata, the depths of which are known from drilling. If no well or subsurface data are available, the speeds can be determined with somewhat less precision from refraction profiles or from special reflection profiles with wide "spreads."

In favorable circumstances depths of reflecting surfaces up to 10,000 ft. can be determined to within less than 50 ft. In other cases individual reflecting depths may be accurately determined but the reflecting layers apparently are not continuous and cannot be definitely correlated from one shot point to another. Where results are definite the reflection seismic method is much the most definite and satisfactory of all the geophysical methods.

Seismic equipment and field practice. A great many types of seismic detectors have been used. Some of the early instruments were purely mechanical, and consisted of a suspended mass and an optical system for magnifying the small movements of the mass relative to its support to permit recording on a photographic tape. Practically all modern field seismographs are electrical. Some depend upon the movement of a coil in a magnetic field, some use the movement of an armature in a balanced magnetic bridge, some use a stack of piezoelectric crystals, and so on. Nearly all have electrical amplifiers to magnify the small initial impulses. Sometimes the electrical or mechanical system is selective as to the frequency to which it responds best. The amplification, either mechanical or electrical, is made large enough so that micro-seisms, or the very small ground movements due to wind, tide or small earthquakes, begin to appear on the records as a background "noise." The maximum useful amplification in terms of the ratio of the amplitude of movement on the detector record to actual ground movement is $6\text{–}10\times10^4$ times, if the detectors and amplifiers respond to all ground movement, but may be 10–100 times greater in a

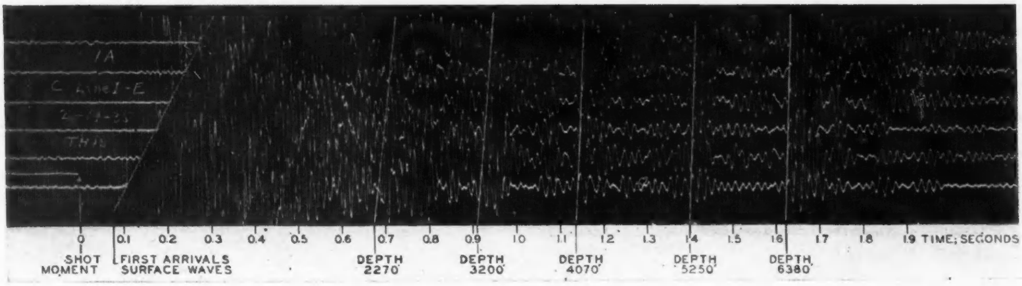


FIG. 13. Sample reflection record, showing reflections from several different depths.

single frequency band if the equipment is selective in frequency.

The arrangement of the field apparatus depends on the type of work being done. In fan shooting the shot point may be several miles from the detectors and the individual detector positions may be a mile or more apart. For such work, each detector has an individual recording unit and communication with the shot point for determination of the shot moment is by radio. The same general methods may be used for shooting long refraction profiles. For reflection work, the individual detectors are connected by cables to a recording truck containing the amplifier and a multiple element oscillograph by which the records from all the detectors are placed side by side on the same photographic tape (Figs. 13 and 14). Contact with the shot point is maintained by a wire laid on the ground, which serves for communication between the shooter and recording truck and also connects to another oscillograph element which marks the shot moment on the record. The oscillograph record is often developed immediately in the field and inspected to see if satisfactory reflections have been obtained. Usually several charges of different intensity are fired for the same set-up to bring out reflections over a wide range of depths.

A considerable amount of surveying is a necessary part of seismograph field work. In reflection work, the elevation of the shot point and each detector must be determined. Also, their position must be determined for mapping the results of the work. In fan shooting, the shot detector distance must be determined accurately. In some of the older work, this was done by running out the recording tape long enough to mark the sound wave from the explosion and calculating the distance from the speed of sound in air. This is hardly accurate enough for precise work, because of the difficulty of making sufficiently accurate corrections for the effects of wind, temperature, etc. on the speed.

A complete reflection seismograph field party will have the following equipment: (Also see Fig. 14) 1. A portable drill, mounted on a truck, and capable of drilling to as much as 200 ft.; such a drill may be able to make several 100-ft. holes per day. 2. A water truck to supply water for loading the shot hole and for drilling. 3. A shooters truck, for carrying dynamite, shooting equipment and telephone. 4. A recording truck, with the amplifiers, oscillograph, developing equipment, etc.; the detector cables and detectors are carried on this truck, or else on a separate, wire truck. The crew of 10 to 20 men required to handle this equipment turn in records for from 3 to 10 shot points per day, depending on the num-

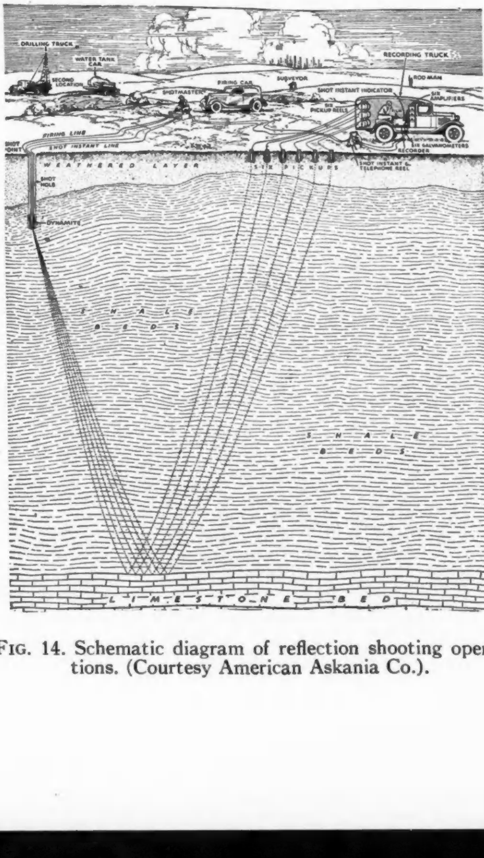


FIG. 14. Schematic diagram of reflection shooting operations. (Courtesy American Askania Co.).

ber of shots required at each point, the difficulty of getting over the ground, the amount and difficulty of the shot hole drilling, etc. The calculation of records and mapping of the results may be done in the field or at central headquarters. Some reduction of the records in the field is usually necessary to direct properly the shooting program.

Geophysical Literature

There is a large volume of literature on applied geophysics, both in periodicals and books. The discussions of theoretical phases are much more complete than are those of practical application. While there are numerous maps and discussions of results of individual surveys, the articles do not contain detailed technical discussions of the apparatus used. This is especially true with regard to seismic developments; the writer knows of no complete technical description of modern seismic prospecting equipment. This, of course, results from the fact that the development and application of seismic methods has been intensely competitive between the various oil and prospecting companies; naturally they have endeavored to keep their development secret.

In the following brief bibliography only readily accessible material in English is given, as this will be of most general interest. Any intensive study would soon lead one into the very extensive material in German, French, Italian, Russian and Japanese books and journals.

Books:

Eve and Keyes, *Applied Geophysics* (Cambridge Press, 1933). About half the book is given to various electrical methods; discussions of the other methods are general and are not up to the date of the book, particularly with regard to seismic methods.

Edge and Laby, *The Principles and Practice of Geophysical Prospecting* (Cambridge Press, 1931). Report of a series of experimental government surveys in Australia, with details of various surveys by all methods except the reflection seismograph.

Heiland, *Directions for the Use of the Askania Torsion Balance* (American Askania Co., Houston, Texas). Detailed manual of field operations with this balance.

American Institute of Mining and Metallurgical Engineers, *Geophysical Prospecting, 1929*, *Geophysical Prospecting, 1932*, *Geophysical Prospecting, 1934*. Geophysical papers presented at meetings of the Institute. Particular mention may be made of the following ones. In the 1929 volume: *torsion balance*, Barton, pp. 416–479, 480–504, Lancaster-Jones, pp. 505–529; *seismic methods*, Barton, pp. 572–624. In the 1932 volume: *gravity interpretations*, Shaw, pp. 271–366; *seismic methods*, Ewing and Leet, pp. 245–262. In the 1934 volume: *reflection seismic methods*, Rutherford, pp. 391–410, Heiland, pp. 411–454, Pugh, pp. 455–472.

Journals:

Physics has published the following papers: *torsion balance and gravity*, Barton, **2**, 29, Slotnich, **2**, 131, Hartley, **2**, 123; *seismic theory*, McCollum and Snell, **2**, 174, Wilson, **2**, 186, Slichter, **3**, 273, Muskat, **4**, 14, Pekeris, **5**, 307; *seismic practice*, Leet and Ewing, **2**, 160, McDermott, **3**, 39, Leet, **4**, 375, Ewing *et al.*, **5**, 165, Ewing and Crary, **5**, 317; *electrical methods*, Peters and Bardeen, **2**, 103, Slichter, **4**, 411, Muskat, **4**, 129, Slichter, **4**, 307, Stevenson, **5**, 114.

Bulletin of the American Association of Petroleum Geologists: most of the geophysical papers, on various methods and with maps of actual surveys, appear in the Sept., 1930, Nov., 1931, Dec. 1932, Jan., 1934 and Jan., 1935 issues. The March, 1935 issue (pp. 356–375) contains actual torsion-balance and seismograph maps of oil field structures.

Reprints of Survey Articles for Class Use

The survey articles that appear from time to time in *The American Physics Teacher* are being used in several physics departments as supplementary periodical readings for students in intermediate and elementary courses. There has been some demand for reprints for this purpose and, as a service to subscribers, arrangements have been made to supply reprints of the following articles at cost:

W. V. Houston, *Role of Positrons and Neutrons in Modern Physics* (May, 1934).

G. P. Harnwell, *Artificial Nuclear Disintegration* (Feb., 1935).

L. L. Nettleton, *Applied Physics in the Search for Oil* (Sept., 1935).

For additional information, address the editorial office of this journal.

The Physics Laboratory at the University of Cincinnati

L. M. Alexander, *Department of Physics, University of Cincinnati*

THE new physics laboratory building at the University of Cincinnati, completed recently at a cost of \$361,000, is a four-story structure built on a hill, with two stories above ground on the south, front, side and four stories above ground on the north side. It is T-shaped, with the longer section 62×149 ft. and the shorter section 49×98 ft. The volume of the building is 886,000 ft^3. and the floor space, not including corridors, is 42,000 ft^2. In addition to the cost of the building, the sum of \$39,000 was spent on apparatus and office equipment.

The construction is reenforced concrete faced with brick and trimmed with Bedford stone. There are four types of floors: terrazzo in the corridors, stairs, and elementary laboratories; maple in the offices, lecture rooms and classrooms; dust proof concrete in the research rooms; and wood block in the shops. The corridors on the third and fourth floors, and all stair wells, have tile wainscot; those on the first and second floors have composition wainscot. The plaster used throughout the building is Portland cement mortar with sand finish; all plaster is painted.

The rooms are disposed as follows:

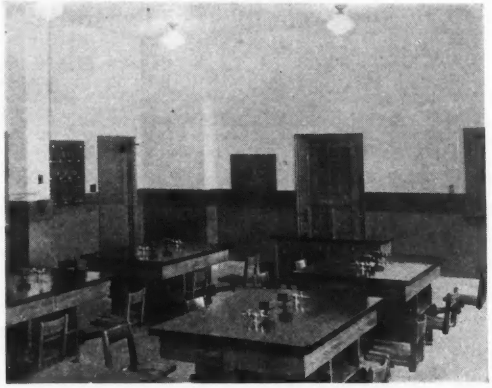
First floor: 2 offices; 7 research rooms; 2 shops; 4 laboratories (heat, optics, spectroscopy, and mechanics); photographic dark room; transformer and machinery room; receiving room.

Second floor: 6 research rooms; 6 laboratories (electronics, electrical measurements, standard measurements, sound, photoelasticity, and x-rays); 2 battery rooms; office; stock room; storeroom; drafting room.

Third floor: 3 lecture rooms, with 219, 116, and 105 seats; lecture-apparatus room; 4, 50-seat classrooms; 8 offices.

Front view of building.

Rear view of building.



An elementary laboratory.

Fourth floor: 5 elementary laboratories; elementary dark laboratory consisting of 8 small rooms; 3 stock rooms; 5 offices; departmental library; staff room.

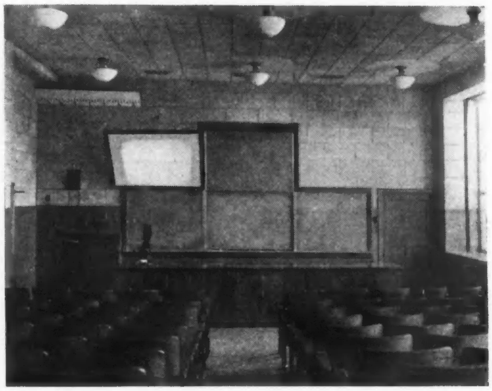
An electric elevator serves the receiving room on the first floor, stock rooms on the second and fourth floors, and lecture-apparatus room on the third floor.

An opening, 12 ft. in diameter, is provided in the roof for a small astronomical dome and telescope which will be installed at some future time.

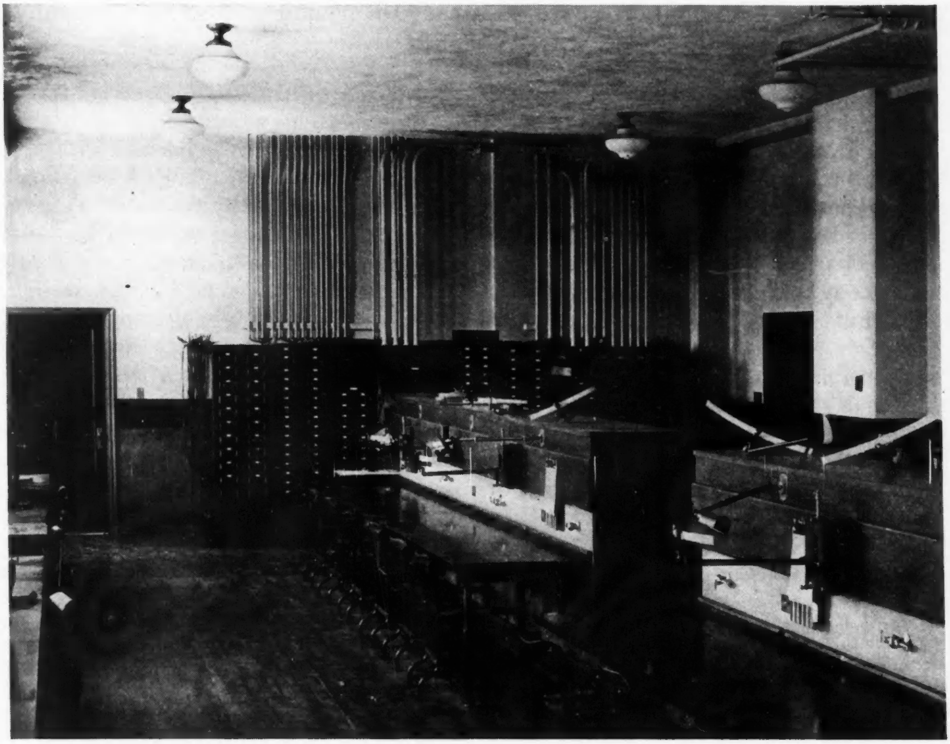
The lecture rooms and classrooms, seven of the laboratories, and the staff room are equipped with unit-type ventilators, supplemented with direct radiation, all thermostatically controlled. The remaining rooms having windows are equipped with direct radiation only. The rooms on the south side of the lower two floors have no windows and are ventilated by means of a single fan. The windows on the south and west sides of the building are equipped with Venetian blinds. On the north side black window shades are used which are invisible from the outside, thus making it unnecessary to pull the shades to a given position in order to dress the windows. The three lecture rooms are equipped with automatic, electrically driven dark shades.

The electric light fixtures in the lecture rooms and classrooms are of the semi-indirect type, with the principal component of light in the upward direction. The intensity of illumination at the working plane is 20 footcandles. These rooms are treated with sound absorbing material, designed to give a reverberation time of 1 sec. when the rooms are empty. Since the acoustic material is difficult to clean and therefore has a variable coefficient of light reflection, a painted plaster surface, 4. ft. in diameter, has been placed flush with the acoustic material around each fixture base on the ceiling. These surfaces are large enough to receive most of the upward component of light from the fixtures and are easily cleaned without disturbing the acoustic material.

The lecture rooms are equipped with reflecting galvanometers, overhead projection lanterns operated from the lecture tables, and special blackboard lighting fixtures, mounted flush with the ceiling at the distance of 3 ft. from the blackboard wall. The lecture tables have compressed air, water, gas and several multi-potential and 110-volt a.c. outlets.



View of lecture room. Notice special blackboard lights and the acoustical treatment.



Electrical measurements laboratory with distribution switchboard.

The elementary laboratories have continuous built-in tables around the walls. Several tables in the central portions of the rooms, each accommodating 4 students, are equipped with gas and water connections, 110-volt a.c. outlets, and outlets on which any potential available may be impressed.

The research rooms are approximately 11×25 ft. Each room is supplied with gas, a deep sink with water connections, a uniform electric panel, and built-in tables which consist of heavy wooden tops on supports made of gas pipe fittings. The wall space in all research rooms and laboratories is equipped with oak boards 11 in. wide and 4 ft. above the floor, for supporting galvanometers and other equipment.

A distribution board in the electrical measurements laboratory makes it possible to connect any of the following potentials to the various outlets in the laboratories, shops, classrooms and research rooms: 110- and 220-volt a.c., single and three phase; 120-volt d.c. by steps of two volts; 120-volt d.c. generator; 800-cycle pure sine wave for impedance measurements. Tapered solid jacks are used in making these connections; we have found from many years of experience that they are much more satisfactory than the small split-type jack.

Approximately 600 students are registered in the courses of the department. They are distributed by years as follows: 10 first, 240 second, 240 third, 100 fourth, and 10 graduate. The departmental staff consists of 3 full professors, 1 associate professor, 2 assistant professors, 3 instructors, 3 laboratory aides, and 1 mechanician.

The staff desires to take this opportunity to express its appreciation of the careful and intelligent work done on the design of the building by the architects, Messrs. Crowe and Schulte.

College Entrance Examination Board—Proposed Revision of Entrance Examinations in Science

AT a meeting of the College Entrance Examination Board in November, 1933, the Subcommittee on Questions of Policy recommended that steps be taken toward the realization of a more nearly continuous secondary school curriculum in science and a comprehensive examination in science to be held by the Board, that a commission to study this plan be appointed immediately, and that as a first step in this direction an effort be made to provide as an alternative to the usual examination in physics a three-hour examination devised to test the extent to which the student has brought to the enrichment of his study of physics the facts and principles learned in earlier studies of biology, chemistry or astronomy.

At the meeting of the Board in April, 1934, the appointment of the following Commission was reported:

Professor Hugh S. Taylor, Princeton University, *Chairman*
Professor George A. Baitsell, Yale University
Professor N. Henry Black, Harvard University
Mr. W. L. W. Field, Milton Academy, Milton, Mass.
Professor Earl R. Glenn, New Jersey State Teachers College
Doctor Ellis Haworth, Washington, D. C.
Professor Karl F. Herzfeld, Johns Hopkins University
Professor Leigh Hoadley, Harvard University
Mr. John C. Hogg, Phillips Exeter Academy, Exeter, N. H.
Mr. Augustus Klock, Fieldston School, New York, N. Y.
Professor Frederic Palmer, Jr., Haverford College
Professor Abby H. Turner, Mount Holyoke College

The report of this Commission which was submitted to the Board in April, 1935, should be of importance to all teachers of physics, chemistry and biology. This report has been made a special order for the meeting of the Board's Committee of Review to be held on Tuesday, October 29, 1935. In the meantime the Secretary of the Board will welcome suggestions and criticisms from those interested. Communications should be addressed to the office of the College Entrance Examination Board, 431 West 117th Street, New York, N. Y.

Report of the Science Commission

The Commission on Examinations in Science, appointed by the College Entrance Examination Board in April, 1934, has conceived its problem as that of making recommendations to the Board on a general policy to be pursued with respect to all examinations in science. Hitherto commissions have been appointed by the Board in the separate subject-matter fields of science with the task of framing definitions of requirements in those special disciplines. The present Commission, composed of representatives of many different fields of science, regards its province as less specialized. This province includes that of defining the proper policy of the Board in the light of current changes, both in secondary school and college instruction, since the increasingly specialized demands of the latter call for a broader understanding of cognate fields. Conceiving its task as thus concerned with science as a whole, this Commission has followed the discussions of the Commission on Mathematics[1] and submits one recommendation which links together the still broader fields of mathematics and science.

Present Examinations

With respect to present examination offerings of the Board the Commission believes that, in view of the costs of developing and reading adequate examinations, the Board should restrict its efforts to the three major subjects: physics, chemistry and biology. *The Commission recommends, therefore, that examinations in botany, zoology, physical geography and mechanical drawing be discontinued.* Current admission practices in colleges permit the certification of subjects in which no examinations are offered by the Board, so that such action would be no disadvantage to schools now offering those subjects, and would enable the Board to concentrate its attack on the improvement of examinations in the fundamental sciences.

With respect to the nature of the present examinations, the Commission is of the opinion that existing examining methods are in some respects inadequate and in need of improvement. *It is therefore recommended that, during the next few years, the Board make an intensive study of the*

[1] Math. Teacher **28**, 154 (1935).

effectiveness of examining procedures in biology, chemistry and physics. Concerning the relative merits of the subjective and objective test procedures, the Commission is of divided opinion and does not wish to make any recommendation other than that this problem be approached empirically. The Commission hopes that a series of experiments will be initiated in the near future with the cooperation of schools and colleges, looking toward the solution of the many baffling problems involved in the construction of proper examinations. The Commission regards many of these problems as open to experimental attack in much the same way as are problems in the specialized fields of science. Such experiments are contemplated and embraced in the foregoing resolution submitted for adoption.

Future Examinations

The Commission sees the evolution in the schools of types of instruction that lead to a scientific training now neither measured by the Board nor encompassed in its definitions of requirements. The Commission feels that the Board should enlarge its concept of examinations in science and seek to set up a series of examinations of a character distinctly in advance of its present series.

The Commission recognizes three levels of attainment now possible of measurement and description:

(1) The first level is that defined in the present requirements. The Commission feels that the study of a single science for a single year, according to present practice, serves only a limited purpose as part of a liberal education. The Commission expresses the hope that this concept of both training and examination will gradually be modified in favor of broader concepts.

(2) The second level is that now reached in many schools where two sciences are taught. The Commission is emphatic on the point that the information, achievement and skill which result from proper instruction in two sciences are not adequately described by asking the candidate to take two separate papers of the first level. *It is recommended, therefore, that the Board offer two new examinations, one in the field of the physical sciences, including physics and chemistry, and the other in the field of the biological sciences.*

The examination in the physical sciences should integrate two years of work, one each in physics and chemistry, such as are already normal in many public and preparatory schools. The Commission is of the opinion that, by such integration, economies of instruction can be achieved in those areas of the subject which are common to the two sciences, with consequent possible extension of subject matter treated. Especially is this true in the treatment of modern theories of atomic and molecular structure and in the studies dependent on the kinetic theory of matter and on the interaction of electricity and matter. Relevant information and methods derived from other sciences might readily be introduced as supplementary material. The examination in the physical sciences should be comprehensive in character. As a substitute for the Board's one-unit examination in science for New Plan candidates who are certified by their schools in another unit of science, the examination at the second level should earn the most serious consideration of colleges and universities ready to carry individuals forward at advanced levels in freshman year. Together with mathematics at the three-year or beta level, such training should be recognized as providing a broad foundation upon which to build the more specialized studies of college years. The Commission emphasizes its view that modern trends in the physical sciences demand an increasingly comprehensive knowledge of the sister sciences and of mathematics. The examination at the second level is an index of the Commission's recognition of such trends.

Similar conditions obtain in the biological sciences, and the comprehensive examination in biological science at the second level should test the student's ability in and grasp of not only the biological principles but also the physical and chemical fundamentals involved in biological processes and investigations. The introduction of quantitative measurements into such investigations is making continuously increasing mathematical demands upon advanced students. Hence, the Commission is of the opinion that the training at the second level in biological science should recognize such trends.

(3) The third level is that achieved by the

students who have passed through the broad fundamental training required at the second level and who are devoting their time intensively to further study in one field of science. To make such intensive study fruitful it is necessary, of course, that the student bring to his work a knowledge of mathematical procedures and considerable mathematical insight. *It is recommended, therefore, that advanced examinations in biology, chemistry and physics be offered by the Board for those students who have passed beyond the second level and who are simultaneously offering four-year or gamma mathematics as a part of their examination program.*

The scheme of examinations recommended here may be summarized as follows:

First level —biology, chemistry, physics

Second level—biological sciences, physical sciences

Third level —biology, chemistry, physics—including mathematics gamma

The Commission feels that the concept of "the unit" as a device for evaluating work in science or equating such work with other school courses may have outlived its usefulness. In fact, it is felt that such a concept applied to the introductory work of the first level may now tend to retard the development of science in the schools. It is obvious that the type of work contemplated at the second level taken in conjunction with the corresponding beta level in mathematics might easily constitute at least a third of the total program on which the candidate bases his claim for admission. The program in which the student reaches the third level and simultaneously offers mathematics gamma might constitute approximately one-half of his offering. The Commission urges that colleges now having regulations which limit the science offering for admission to one or two units consider the possibility of allowing students to extend their preparation in the fundamental sciences in school.

The Commission does not consider that the redrafting of the present definitions of requirements or the framing of new requirements falls within its scope. The present definition of requirements in biology was adopted November, 1932, that in chemistry in April, 1927, and that in physics in April, 1921. In April, 1933, the Board voted "that the existing definitions of the requirements be liberally interpreted as indicating in a general way the nature and extent of preparation considered necessary and not as prescribing any definite form of instruction, method of preparation or teaching technique." This regulation permits sufficient elasticity of procedure to enable the schools to proceed in the spirit of this report under the old definitions. When new definitions are indicated, the problem should be referred to subject-matter specialists working together to evolve a comprehensive program of instruction, rather than to a general committee on examinations. The work contemplated at the second and third levels would be hampered at the present time by attempts to define the curriculum.

Concerning the Program for the St. Louis Meeting

A PART of the program at the next annual meeting at St. Louis will be devoted as usual to contributed papers. Members who wish to submit papers should send the titles as soon as possible to the secretary, Professor Wm. S. Webb, Department of Physics, University of Kentucky, Lexington, Ky. An abstract of 200–400 words, prepared in a form that is suitable for publication, must be in the hands of the Secretary by November 15.

Positions Wanted by A.A.P.T. Members

The physicists whose announcements appear here are not at present employed in professional capacities. Representatives of departments having vacancies are urged to obtain from the editorial office of this journal additional information concerning those whose announcements interest them. *The existence of a vacancy will not be divulged to anyone without the express permission of the department concerned.* Any information or suggestions that will be of possible help in assisting these physicists to obtain positions of a professional nature is invited.

1. Ph.D. Cornell, S.B. Denison. Married. 20 yr. teaching experience, including 5 yr. assoc. prof. state college and 5 yr. head of dept., southeastern univ. Special interest in undergraduate teaching and in building and adapting laboratory apparatus to suit the needs of the student.

2. Ph.D. Indiana, M.S. Kansas State, A.B. Friends Univ. Age 31, married. 2 yr. asst. instr. state univ.; 1 summer, instr. Kansas college. Special fields: conduction of heat and electricity in metals; electrical communication; physical chemistry. Desires position in undergraduate teaching or industrial research.

3. Ph.D. Univ. of Washington, B.S., M.A. Northwestern. Age 45, married, no children. 11 yr. civil engineering work; 15 yr. teaching physics, including 8 yr. college in Orient and 4 yr. head dept. western coed. college. Special fields: magnetism, engineering physics, history of physics. Experienced administrator and executive.

4. Ph.D. Cornell. Age 38, married. 11 yr. teaching in both men's and women's colleges in East and South. Research in electron physics. Special interest in development of demonstration lectures, laboratory experiments and equipment. Glass blowing.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge. Departments of physics having vacancies of any kind and industrial concerns needing the services of a physicist are invited to make known their wants through the columns of this journal; there will be no charge for the service. For additional information, address the Editorial Office, *The American Physics Teacher*, University of Oklahoma, Norman, Oklahoma.

Symposium on Instruction for Premedical Students

At the next annual meeting of the Association of American Medical Colleges in Toronto, Canada, October 28, a symposium will be held for the purpose of bringing about a better understanding of the aims of liberal arts colleges and medical schools so far as study preparatory to entering the latter is concerned. Six invited papers will be given: three by members of liberal arts faculties, a physicist, a chemist and a biologist; and three by members of medical faculties, an anatomist, a physiologist and a biochemist. Professor K. K. Smith of Northwestern University has been selected by the American Association of Physics Teachers to represent the physicists; his subject is *Physics and the Premedical Student.* A paper on the subject, *The Physical Sciences in the Training of the Physician* will be given by Dr. R. K. Cannan of the New York University College of Medicine.

It is believed that this symposium will serve to bring about better cooperation and understanding between the medical and liberal arts colleges than any other effort in that direction that has previously been made. The Association of American Medical Colleges, through its secretary, Dr. Fred C. Zapffe, Chicago, Illinois, has extended a cordial invitation to all physicists who can do so to attend this meeting and to participate in the discussion.

The Association of American Medical Colleges plans to send a printed copy of the papers given in the symposium to every physics department that prepares students for the medical schools. Any one who has a special interest in physics for premedical students may make sure that his department receives a copy by sending his address to the editorial office of this journal.

THE deliberate effort to follow immediate utility almost invariably leads to second or third rate work, and more often than not the very utility which is narrowly sought turns out to be not so great after all.—E. T. BELL, in *The Queen of the Sciences.*

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

A Simple Device for Focusing a Spectrometer Telescope for Parallel Light

ALFRED H. WEBER, *Lonergan School of Mechanics, St. Joseph's College, Philadelphia, Pennsylvania*

EVERY laboratory instructor has experienced the inconvenience associated with focusing the telescopes of spectrometers and spectroscopes for parallel light. It is usually necessary to carry the spectrometer as a whole, or at least the telescope, from the dark room to another room and there focus on a distant object. This is usually done by sighting through an open window. The device here described eliminates the need of leaving the dark room laboratory, or even of detaching the telescope, to accomplish the adjustment of the telescope for distant vision.

In Fig. 1, *L* is a double convex lens of short focal length (5 cm) with the edges ground down to fit into the end of a short piece of brass tubing. The brass tube *A* is 7/8 in. inside diameter and $2\frac{1}{4}$ in. long. On the end of this tube is soldered a brass disk with a $\frac{1}{4}$-in. central circular aperture, *O*; this is a diaphragm. A brass tube *B*, $\frac{3}{4}$ in. long, fits into the tube *A* as a draw tube and is fixed in place by the set screw *C*. The tube *B* carries a photographic negative of a scale in the end at *S*. Tubes *A* and *B* have their inside surfaces blackened. A flat disk *D* is soldered to the device so that it may rest on the spectrometer table without rolling.

The principle of operation is extremely simple. The scale *S* is placed in the focal plane of the lens *L*. If now the device is placed on the spectrometer table (Fig. 2) with the scale *S* illuminated suitably from behind, the scale may be observed by sighting the telescope on it through the aperture *O*. Since the scale is in the focal plane of the lens, the light rays emerging from the aperture are parallel. Thus, the telescope must be focused for parallel light in order to view the scale most distinctly.

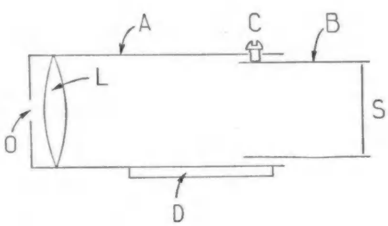


FIG. 1. Diagram of the focusing device.

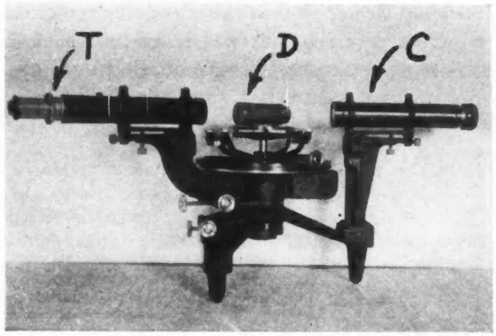


FIG. 2. *T*, telescope; *D*, focusing device; *C*, collimator.

In practice, the scale is adjusted to lie in the focal plane of the lens *L* by the following procedure. The spectrometer telescope is independently focused on a distant object and is then sighted through the aperture of the focusing device as already explained and as shown in Fig. 2. Sharp focus is secured by moving the draw tube *B* in or out. Since the telescope is adjusted for parallel light the scale must now be in the focal plane of the lens. The screw *C* is then tightened and the device is ready for use without further adjustments.

The device is effective only when used with a good sharp scale having very small divisions. The scales of the type used in the scale tube of prism spectroscopes are excellent for this purpose.

A Simple Method for Studying the Variation with Temperature of Young's Modulus for Certain Metals

J. E. CALTHROP AND J. T. MILLER, *Department of Physics, Queen Mary College, London, England*

THE variation of Young's modulus with temperature may be investigated by a simple method and with results over a range of some two hundred degrees above air temperature that are in fair agreement with those of other workers.[1] The arrangement may be set up with ease in any laboratory and it is thought that the exercise may prove useful for the more advanced student.

The material to be investigated is taken in the form of a wire of about 0.15 cm in diameter, and is made into a ring of some 25 cm in diameter (Fig. 1). The ring is split and the ends joined to insulating cylinders C of Bakelite, so that it can be heated electrically. The mean temperature of the wire may be determined from the variation of the resistance as found from the current and from the potential difference between the terminals AB. Appropriate loads W may be applied to the lowest point of the ring.

Let Wg be the load in dynes; r, the radius of the ring; a, the radius of the wire; d, the depression of the lowest point of the ring; I, the moment of inertia of the wire section about a diameter; and E, Young's modulus of the material. Then[2] $E=0.298Wgr^3/2dI=0.19Wgr^3/da^4$. For our main purpose, we notice that E varies inversely as d. From a series of depression-load curves obtained for different temperatures of the ring, all the required information may be deduced.

In Figs. 2 and 3 are shown typical results for a nichrome specimen, for which r and a were 24.8 and 0.075 cm, respectively. If we assume in

[1] C. H. Lees and J. P. Andrews, Proc. Phys. Soc. **36**, 405 (1924); **37**, 169 (1925); Kimball and Lovell, Phys. Rev. **26**, 121 (1925); Keulegen and Houseman, Bur. Standards J. Research, **10**, No. 3 (1933).

[2] W. Sucksmith, Phil. Mag. **8**, 158 (1929).

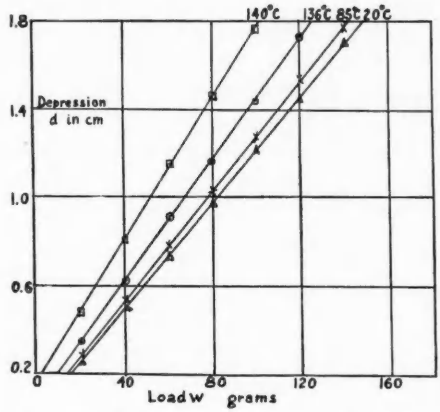


FIG. 2. Depression-load curves for various temperatures.

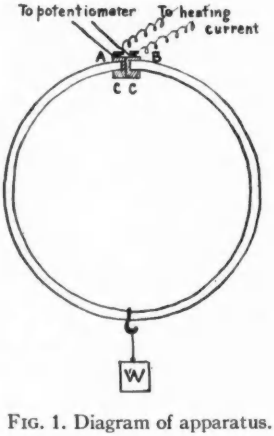


FIG. 1. Diagram of apparatus.

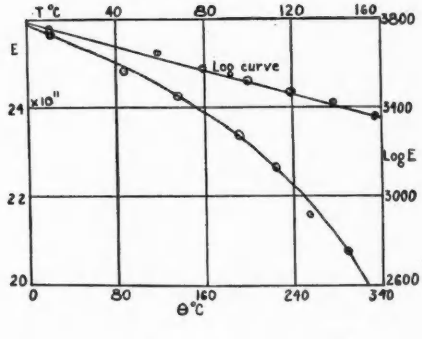


FIG. 3. Lower curve: E *vs.* θ. Upper curve: log E *vs.* θ.

agreement with other workers that E is $E_0e^{-K\theta}$, where K is a constant and θ is the temperature, we should get a linear relation on plotting log E against θ and also $-dE/E\,d\theta$ should be constant. In Fig. 3 it may be noticed that a reasonably straight line is obtained.

The following values were obtained for K: nichrome 49; brass 34; steel 25; aluminum 19; phosphor bronze 34; tungsten 8.6; manganin 19, all $\times 10^{-5}$. Nichrome and manganin are not mentioned by other authors. It should be said that the change of dimensions due to expansion has been neglected because this is small except for aluminum.

Double Purpose Brackets for a d'Arsonval Galvanometer

I. A. Balinkin, *Department of Physics, University of Cincinnati*

WHENEVER a d'Arsonval galvanometer is not in use and the table space below the galvanometer is desired for other experiments, the problem presents itself of removing the arm to which the scale and the telescope are attached. The parts removed are rather cumbersome to store. For convenience of storage the scale is frequently turned in the direction along the axis of the telescope and, consequently, new adjustments are required for the setting of the scale and the telescope when they are placed back for use.

The usual brackets for holding the arm of the galvanometer consist of two flat pieces of metal shaped in the form of hooks and attached to the sides of a wooden board on which is mounted the galvanometer. The arm of the galvanometer is forked and is provided with two studs which project out and engage from the inside with the flat hooks.

The inconveniences connected with the storing of the scale and telescope can be easily avoided by employing longer brackets (Fig. 1) that permit the setting of the galvanometer arm in a vertical position with a slight leaning toward the wall. Each bracket is provided with two hooks, one for holding the arm in its regular working position, and another for storing in an inclined vertical position

It is also possible to modify the form of the connecting fork of the galvanometer arm so that a single-hook bracket will hold the arm either in a horizontal or an inclined vertical position If the described method of storing the scale and telescope finds favor with other laboratories, as it did with us, manufacturers may be interested in changing the design of the arm so that a bracket with a single hook will serve the double purpose.

Fig. 1. D'Arsonval wall galvanometer with double purpose brackets, showing the scale and the telescope in a working horizontal position and in an inclined vertical position for storing purposes.

A Simple Laboratory Apparatus for Experiments in Dynamics

WALTER SOLLER, *Department of Physics, University of Arizona*

THE need for more laboratory experiments of an elementary nature on the laws of dynamics has led to the development of an apparatus that is not only easy to construct and operate, but that provides experiments which involve most of the dynamical principles studied in the first-year course.

The apparatus, Figs. 1 and 2, is essentially a weight-driven motor in which the load is applied by means of a prony brake. The fine cable attached to the weight goes over a pulley fastened to the ceiling and is wound on a small shaft of the motor. On this shaft is a steel motor pulley around which the belt of the prony brake is held in place by two spring scales. A removable handle is used to wind up the apparatus. The position of one of the spring scales is adjusted to obtain the desired load on the motor for a given driving weight.[1]

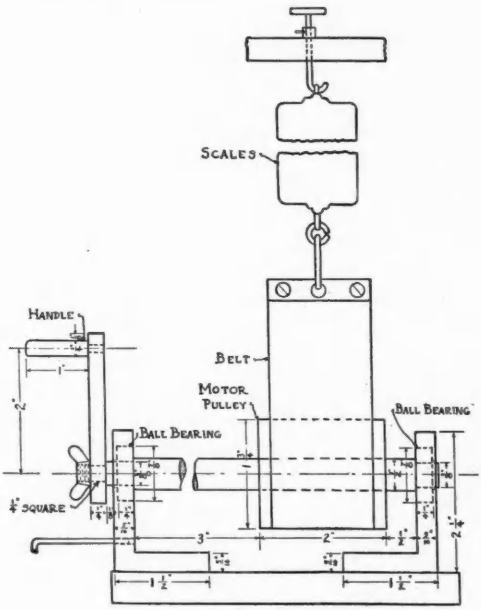


FIG. 2. Side view of apparatus.

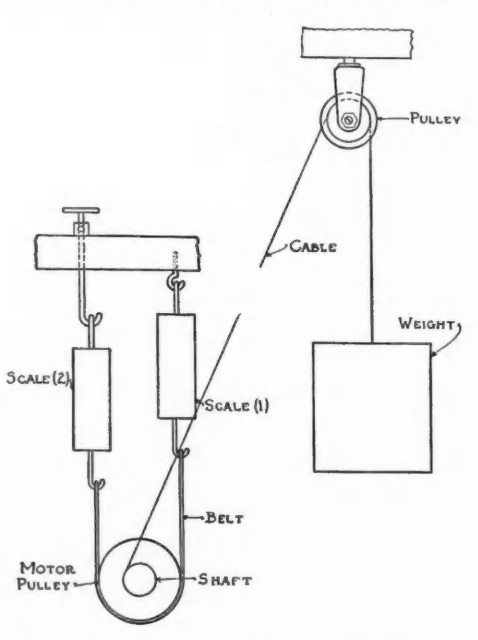


FIG. 1. Diagram showing front view of apparatus.

To perform the experiment the weight is allowed to drop with a constant acceleration, and the following quantities are recorded: mass, m, height of fall, h, and time of fall, t, of driving weight; readings of scales during fall, f_1 and f_2; mass, m_1, and radius, r_1, of shaft; mass, m_2, and radius, r_2, of motor pulley. From these data the following quantities are calculated: the load or net force on the belt, $f_0=f_1-f_2$; useful work done, $W_0=f_0hr_2/r_1$; speed of weight at bottom, $v=2h/t$; moment of inertia of motor, $I=(m_1r_1^2+m_2r_2^2)/2$; angular speed of motor at instant weight reaches bottom, $\omega=v/r_1$; total kinetic energy of motor and weight at instant weight reaches bottom, $W_k=(I\omega^2+mv^2)/2$; potential energy of weight at top, $W_p=mgh$; work done against load and friction, W_p-W_k.

From these quantities the efficiency of the

[1] List of materials: motor spindle, cold drawn steel, 1/2″×7″; motor pulley, cast iron or steel, 1-3/4″ diameter, 2″ long; motor bearings, flat brass, 5/16″×1-1/4″×3-3/4″; motor ball bearings, 3/8″ I.S. diameter, 7/8″ O.S. diameter, 1/4″ long; wooden base, 1″×8″×8″; scales supporting frame, 2 pieces of wood 3/4″×2″×18″, 1 piece of wood 3/4″×2″×8″, 2 corner brackets; scale adjusting hook, 3/16″ diameter, 4″ long, 3/8″ diameter bushing with set screw; 2 2000-g spring scales; belt, heavy canvas cloth or light leather; 22 ft. of 7-strand, 1/64″ airplane cable; cable pulley, 2 in. diameter; weights, 1/2 to 6 kg.

motor, $W_0/(W_p-W_k)$, the work done against friction, $W_p-W_k-W_0$, and the frictional force $(W_p-W_k-W_0)/h$ can be calculated.

A somewhat more complicated experiment can be performed by fastening two fan blades on the motor shaft. A driving weight of mass m', when the net force f_0 is on the belt, will now cause the motor to operate at a constant speed, v' and with a power input $m'gv'$. The useful load in this case is furnished by the fan as well as the prony brake. The frictional force, f_f, can be determined by removing the fan blades and replacing m' by a larger mass m, such that $m'g=m(g-a)$, where a is the acceleration of m when the net force on the belt is f_0. The efficiency with the fan blades on is $(I\alpha+f_0r_2)(v'/r_1)/m'gv'$, where I is the moment of inertia of the motor pulley and shaft, and α is the angular acceleration due to the driving weight m. The efficiency is also given by $(m'g-f_f)/m'g$.

A Radio Tube Demonstration

Austin J. O'Leary, *Department of Physics, College of the City of New York*

THE control action of the grid of a vacuum tube is commonly demonstrated by using a milliammeter or shunted galvanometer to indicate stoppage of the plate current when a charged ebonite rod is waved within several feet of a wire attached to the grid. For a more spectacular effect, a neon glow lamp, s14 bulb, may be used in place of the meter or in series with it. Plate current, supplied from either an alternating or direct-current 110-volt circuit, causes all but an occasional lamp of this type to glow brightly. The lamp is extinguished when current is prevented from flowing by a negative potential on the grid. This may be accomplished by a wave of the ebonite rod at any point near a grid aerial extending to any desired distance around the room. A vacuum tube such as the No. 30 or No. 299 is most convenient since the filament current is only 60 ma and the filament may be heated from the 110-volt circuit by using a 10-watt, 2000-ohm resistor in series.

A relay in the plate circuit is frequently used to turn an ordinary lamp off and on. A variation of this circuit, employing a flasher sold at most 5 and 10 cent stores, is shown in Fig. 1. The 25-watt lamp serves as a convenient filament resistance for the 201A tube. When this unit is connected to the house-lighting circuit, the heating coil of the flasher causes the bi-metal bar to expand until it produces a short circuit across the coil and allows the normal current to flow through the lamp and filament. With the filament heated, the plate current closes the relay so that the lamp and filament remain lit after the expansion-bar cools.

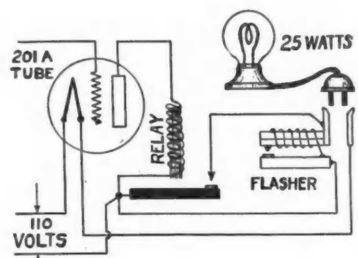


Fig. 1. Circuit with flasher.

One wave of the charged ebonite rod near the aerial extinguishes the lamp. If the rod is now removed completely, the lamp will remain out until the expansion-bar has again become heated. The time lag resulting from the flasher in the circuit makes the demonstration as successful in humid weather as in dry.

THE great desideratum for any science is its reduction to the smallest number of dominating principles.—*J. Clerk Maxwell, "Matter and Motion."*

A New Thermal Conductivity Apparatus

A. L. FITCH, *Department of Physics, University of Maine*

THE formula for the heat conducted through a sheet of any material normal to the faces of the sheet shows that the thermal conductivity of the material could be found if the difference in temperature between the faces could be determined. The temperatures of the two faces may be maintained nearly constant by placing massive blocks of a good conducting material on the two sides of the sheet. If one of the blocks is kept at a constant temperature, the other one, if properly insulated, will change in temperature because of the conduction of heat through the sheet separating them. The temperature difference between the blocks can be determined most readily by means of a thermocouple.

The instrument shown in Fig. 1 was designed to test poor conductors. It consists essentially of two highly polished, flat, nickle-plated copper blocks with suitable thermocouple connections and heat insulation. The lower block is approximately 4.4 cm in diameter and has a mass of 346 g. It is imbedded in a good insulating material and has a copper-constantan thermo-junction imbedded at its center. The copper wire runs out to a copper binding post and the constantan wire runs out to a second, insulated copper binding post with a constantan nut. The upper block serves as the bottom of a well-insulated vessel with a capacity of about 800 ml. This block has a diameter of about 8.4 cm and an unknown mass. The thermal junction in this block is near one edge. The wires run out to copper binding posts and the constantan wire is held by a constantan nut as in the case of the lower block.

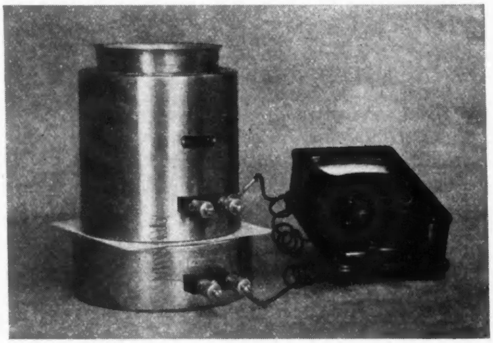


FIG. 1. Photograph of thermal conductivity apparatus.

In use, the upper vessel is filled with boiling water, melting ice, solid carbon dioxide or any convenient bath that will give the temperature at which the measurement is to be made. The material to be tested is placed over the lower block and the vessel with the upper block is placed directly on this. It is necessary that good thermal contact be made between the sheet of material tested and the blocks unless the sheet is very thick. With soft materials, the weight of the upper vessel is sufficient to provide good contact. With hard materials, such as glass, thick plates must be used, or the surfaces may be wetted. A thin film of air will cause more error than a large error in the measurement of the plate thickness. A low resistance galvanometer is connected by copper wires to the copper binding posts and the posts with the constantan nuts are connected by a constantan wire. The galvanometer reading is a measure of the temperature difference between the two blocks. If this difference is sufficient to throw the galvanometer off scale, one may shunt the instrument or wait until the temperature difference becomes smaller. The former method seems to be preferable.

The relations between the galvanometer readings and the other quantities involved are shown as follows. The small quantity of heat conducted through the sheet to change the temperature of the lower block an amount $\Delta T'$ is given by the expression $\Delta H = cM\Delta T'$, where c is the specific heat of the lower block and M is its mass. Since this heat went through the sheet under test, we also have

$$\Delta H = kA(T - T')\Delta t/L,$$

where k is the thermal conductivity sought, A is the area of the lower block in contact with the sheet, T and T' are the temperatures of the upper and lower blocks, respectively, L is the thickness of the sheet and Δt is the time required for the quantity ΔH to flow through the sheet. These

two expressions are for the same quantity of heat; therefore

$$cM\Delta T' = kA(T - T')\Delta t/L. \tag{1}$$

If the galvanometer deflection, N, is proportional to the temperature difference between the blocks, and for this thermocouple it is true for moderate temperature differences, one may write $T - T' = aN$, or $-dT' = adN$. In the limit Eq. (1) becomes $-cMadN = kAaNdt/L$, from which $-dN/N = kAdt/cML$. Upon integration this becomes

$$\log_e N_0/N = kAt/cML. \tag{2}$$

By rearranging and changing to common logarithms, one obtains

$$\log_{10} N = \log_{10} N_0 - kAt/2.303cML. \tag{3}$$

It is clear from this that when values of log N are plotted as ordinates and values of t as abscissas, a straight line results, the slope of which is given by

$$S = -kA/2.303cML. \tag{4}$$

If one prefers he can make the plot on semilogarithmic paper and get the straight line directly without having to look up logarithms.

Fig. 2 was plotted from data taken with a piece of glass 0.646 cm thick used as the test specimen. The galvanometer readings, made at 30-sec. intervals, were: 15.3, 15.0, 14.5, 14.0, 13.2, 12.8, 12.0, 11.5, 10.3, 9.9, 9.2, 8.9, 8.3, 8.0, 7.7, 7.1 divisions. The slope of the line is -0.00081 sec.$^{-1}$, from which one computes the thermal conductivity of the glass to be 0.00255 cal·cm^{-1}·sec.$^{-1}$·deg.$^{-1}$. It is to be noted that the data for this result were obtained in less than ten minutes.

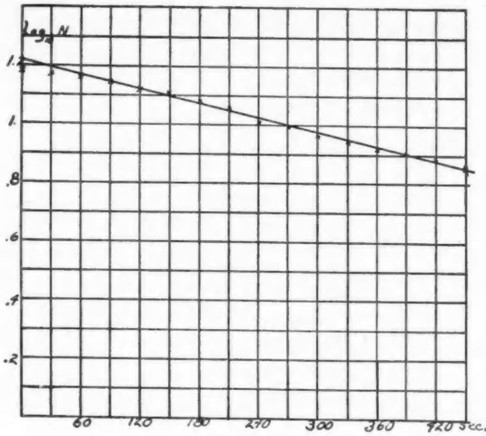


FIG. 2. Plot of $\log_{10} N$ and t.

If the student is not familiar with the calculus, he may plot the galvanometer readings as ordinates and the times as abscissas, and integrate graphically. The integral of Ndt will be the area under the curve from the vertical axis out to the time t, and the integral of dN will be the difference in the values of N at $t=0$ and at t. The results of this computation will agree closely with those obtained by the other method. The accuracy of either method is determined by the care that is taken in drawing the line through the plotted points.

The author wishes to thank the Central Scientific Company for the care taken in the construction of this instrument and for the valuable assistance given in its development.

MINDS that are stupid and incapable of science are in the order of nature to be regarded as monsters and other extraordinary phenomena; minds of this sort are rare. Hence I conclude that there are great resources to be found in children, which are suffered to vanish with their years. It is evident, therefore, that it is not of nature, but of our own negligence, we ought to complain.—MARCUS FABIUS QUINTILIAN.

DISCUSSION AND CORRESPONDENCE

A Practical Method for Reducing Grades to a Common Standard

THE following statements are held to be true: (1) Grades must always rest on someone's opinion, (2) there are no absolute standards for grading, (3) the exact grade is most important to the top 15 percent and to the bottom 15 percent of a class, (4) instructors cannot easily make tests of equal difficulty, (5) the standard error curve is not applicable to small classes, (6) unless grades are reduced to a common mean and a common standard deviation from the mean, an arithemetical averaging of grades does not give equal weight to the different grades, (7) the use of a passing grade dependent on the class mean is a useful aid in the administration of tests, (8) many students and teachers are accustomed to think in terms of percentages running from 0 to 100, (9) students of statistics have shown the need of reducing grades to a common basis before comparing or averaging, but have not given a practical method for this reduction, (10) busy instructors will not spend hours studying grades and they do not have clerks to do the work for them.

With these ideas in mind the following method is suggested for reducing grades to a common standard; while not mathematically rigorous, it is rather simple and is sufficiently accurate for most purposes. Let x represent a "raw" grade; N, the number of grades; σ, the standard deviation, defined by $\sigma=(\Sigma x^2/N-(\Sigma x/N)^2)^{\frac{1}{2}}$; M, the arithemetical average, defined by $\Sigma x/N$; and y, a corrected grade. On a sheet of millimeter coordinate paper, locate on the x axis the points 0, $M-\sigma$, M, $M+\sigma$ and 100 and locate on the y axis the points 0, 30, 50, 70 and 100. Then draw a broken line through the points (100, 100), ($M+\sigma$, 70), (M, 50), ($M-\sigma$, 30), and (0, 0), as in Fig. 1.

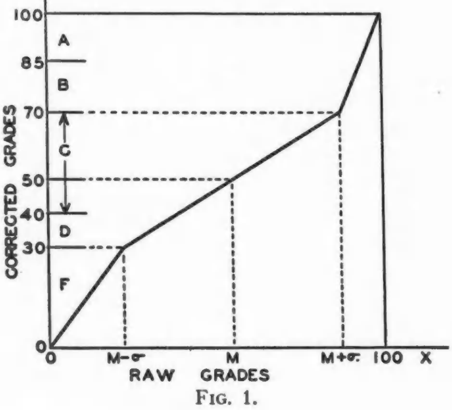


FIG. 1.

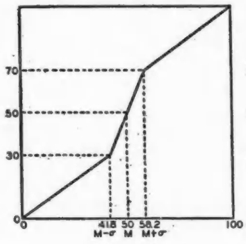


FIG. 2.

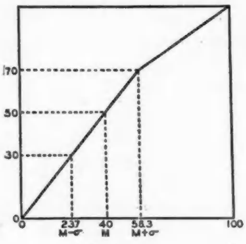


FIG. 3.

The corrected grade, y, corresponding to any raw grade, x, can be read from this graph.

The choice of corrected grades of 30 and 70 to correspond to raw grades of $M-\sigma$ and $M+\sigma$ is purely arbitrary. The use of numbers nearer 50 piles up the grades around the class average and increases the "spread" at the ends. The choice of 30 and 70 seems to be quite satisfactory. When it is desired to express the final grades with the customary A, B, C, D, F, the choice of boundaries depends entirely on the wishes of the instructor. The ranges of "letter grades" indicated in Fig. 1 are suggested. When "F" is given to those who make less than $M-\sigma$, about 16 percent will fail if the method is applied to enough students so that the normal error curve applies. It is strongly urged that the boundaries be chosen before applying the method and then not changed until the choice has been found to be utterly wrong.

The following simple example illustrates the use of the method:

Student	A	B	C	Class av.	σ
Test 1	40	50	60	50	8.2
Test 2	60	40	20	40	16.3
Arith. av.	50	45	40		

These students really have done equally good work if the tests are to be given equal weight. Figs. 2 and 3 are the charts for these two sets of grades. From them the following corrected grades are read:

Student	A	B	C	Class av.	σ
Test 1	29	50	71	50	17
Test 2	73	50	26	50	18
New av.	51	50	49		

The fact that the new averages are not identical shows that the method is not perfect; however, few grades are accurate to 1 percent.

This method has been tried by a number of teachers under a variety of conditions and has been rather successful. It cannot be defended against all criticisms; yet some method of reduction of grades is surely needed and this is a beginning. If someone has a better one, I shall be delighted to use it.

NIEL F. BEARDSLEY

Department of Physics,
University of Chicago.

Why Only Two Specific Heats of a Gas?

THE term *specific heat* when applied to a gas without some qualification is indefinite, since there is the possibility of an infinite number of specific heats corresponding to the various ways in which the pressure and the volume may change during the rise of temperature. The limiting values are the *specific heat at constant pressure* and the *specific heat at constant volume.*

This fact, however, appears not to be emphasized sufficiently in the majority of the elementary college textbooks. The writer has examined 23 standard textbooks for general physics, and in only 5 does he find the matter fully and clearly explained. Four of the 23, curiously enough, mention only the specific heat of a solid or a liquid. The remainder define and discuss only the two special specific heats of a gas. Some make such statements as, "A gas has two specific heats." Some have a section with the caption, "The two specific heats of a gas." This is certainly misleading. True, some of the books, while mentioning only two specific heats of a gas, do discuss the fundamental principles of internal and external work and it should be possible for a good student to reason out that there are intermediate possibilities. However, students almost invariably get the impression that there can be only the two cases which are emphasized in the textbooks.

Perhaps authors have thought it unnecessary to discuss anything more than what is actually used in practice. Or has there been a certain amount of inertia in following a bad precedent? It seems to the writer that the subject of specific heats of a gas is of sufficient importance to warrent a clear and accurate exposition.

W. L. CHENEY

Department of Physics,
The George Washington University.

The Dynamo and Motor Rules, Again

AS supplementing the very elegant formulation of Fleming's rules given by Professor Arthur T. Jones,[1] may I offer the following alternative which has the merit of using only one rule to cover both cases?

Look along the direction of the magnetic field: then, a right-handed rotation of 90 degrees will always bring the effect into coincidence with the cause.

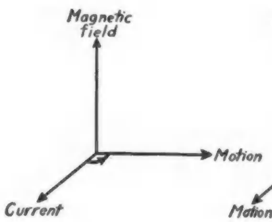


FIG. 1.

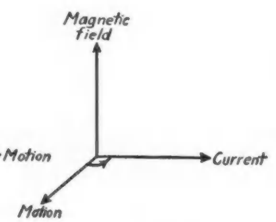


FIG. 2.

In the case of a generator, the effect is evidently the current; but in the case of the motor, it is clearly the motion. A moment's consideration shows that Fig. 1 represents the generator, and Fig. 2, the motor. One axis having been selected to represent the magnetic field, there are only two permutations of the remaining axes; and hence it is almost impossible to make a mistake in applying the rule.

This form of statement was brought to my attention many years ago; but by whom, I regret to say, I have now entirely forgotten. It is not my own.

HENRY CREW

Northwestern University.

[1] A. T. Jones, Am. Phys. Teacher 3, 86 (1935).

Two More Catch Questions

THESE two problems are submitted in continuation of the list Professor Condon has begun.[1] If by a "catch question" is meant something trivial but tricky, intended to embarrass more than to instruct, then his problems are misnamed. They are of real value and importance.

1. Uniform and flexible rope of mass 2 lb./ft. is drawn from a stationary coil by a man who walks at the rate of 5 ft./sec. directly away from the coil over a smooth and level floor. He thus drags after him an increasing length of rope. What horizontal force must the man exert on account of the inertia of the rope? If one takes force as the time rate of change of momentum he gets a certain answer, but if he sets the work done equal to the kinetic energy of the rope an answer half as large is obtained. Which (if either) is correct? Account quantitatively for the difference.

2. Flexible rope of mass 2 lb./ft. is coiled on the ground, with one end tied to a 20-lb. weight. The weight is thrown upward with an initial speed of 30 ft./sec. It rises and pulls after it an increasing length of rope. With what kind of motion, and how high, will it rise? Describe the motion by giving the coordinate of the weight in terms of the time.

W. W. SLEATOR

Department of Physics,
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[1] E. U. Condon, Am. Phys. Teacher 3, 85 (1935).

A Simple Demonstration of the Effect of a Shunt

An obviously simple but very vivid demonstration of the effect of a shunt can be given in an undarkened room with four 60-watt incandescent lamps connected in *series* in the lighting circuit. If a piece of copper wire is used as a shunt around one or two of the lamps, these lamps cease to glow while the remaining ones become brighter. When the shunt is around three lamps the remaining one attains normal brightness. The changes in brightness are sufficient to make the experiment rather striking.

ARTHUR TABER JONES

Department of Physics,
Smith College.

Brief Notices of Recent Publications

First Year College Textbooks

An Introductory Course in College Physics. Newton Henry Black, Assistant Professor of Physics, Harvard University and Radcliffe College. 714 p., 647 fig., 24 portraits, 15×22 cm. *Macmillan*, $3.50. This book was prepared primarily for college students who have not studied physics. It is characterized by the same great clearness and simplicity of statement, and somewhat the same kind of treatment and arrangement, as Black and Davis's *Practical Physics* and Jackson and Black's *Elementary Electricity and Magnetism*. Much use is made of applications in everyday life and in industry. There are many solved examples and many well-graded problems, all quantitative in nature and with answers given in a separate pamphlet. Each chapter has an excellent summary and an annotated list of references.

Elements of Electricity. Anthony Zeleny, Professor of Physics, University of Minnesota. 2nd ed. 526 p., 327 fig., 17 portraits, 15×21 cm. *McGraw-Hill*, $3.50. In this new edition, many topics have been altered and modernized, the chapter on alternating currents has been enlarged, the treatment of the e.m.f. impressed on a conductor by a moving magnetic field has been revised, and three appendixes have been added. There are many qualitative questions, suggestions for experiments, and problems with answers. Basic principles are presented in the first two-thirds of the book. Although intended as a textbook for a course to follow elementary mechanics and trigonometry, the book also should be very useful for reference purposes in the ordinary, first-year course.

Physics for College Students. A. A. Knowlton, Professor of Physics, Reed College. 2nd ed. 623 p., 429 fig., 16×23 cm. *McGraw-Hill*, $3.75. The most significant change in this edition is the collection of the material into the familiar divisions of elementary physics, with electricity, light and much of the "new physics" placed in the second half of the book. Some of the definitions and results have been rendered more explicit, with consequent greater emphasis on the more elementary topics. Problems of a qualitative nature have been added. The first edition of this book did much to broaden our conceptions of the possibilities of the first-year course and it seems safe to say that its appearance will come to be regarded as something of a landmark in college physics teaching and textbook writing in this country. The treatment is broad and yet quite thorough. It is charming and human, and succeeds to a remarkable extent in being intimate in style without at the same time being condescending and ingratiating. There is a certain amount of wordiness and a number of topics that some would like to see treated differently. But if there seem to be faults, this may be partly because we are prone to find such things in any textbook that is very original in its conception.

Reference Books for Beginners

Faraday. Thomas Martin. 144 p., 12×19 cm. *Duckworth* (London), 2/- net. A brief intimate account, with many interesting anecdotes, that reveals the lovable character and humanness of this prince of experimentalists. It is refreshing to be reminded of the great pains that Faraday took in preparing his demonstration-lectures and of his delight in the Christmas lectures to children. The children, says a contemporary, "felt as if he belonged to them; and indeed he sometimes, in his joyous enthusiasm, appeared like an inspired child." Faraday and Darwin are the only scientists represented in the "Great Lives" series of 65 biographies for laymen of which the present book is a part.

Newton and the Origin of Colours—A Study of One of the Earliest Examples of Scientific Method. Michael Roberts and E. R. Thomas. 133 p., 13 fig., 8 pl., 13×19 cm. *G. Bell*, 3/6. An excellent, brief account of Newton's life and his contributions to optics and color, with many quotations from source literature and frequent references to the nature and development of the scientific method. The book is one of a series of "Classics of Scientific Method," intended "to provide reproductions of the great masterpieces of science in convenient form, together with a complete account of the action and reaction of ideas which . . . led up to the crucial experiments carried out and described by some great master." Alex. Wood's *Joule and the Study of Energy* belongs to the same series.

Weather Proverbs and Paradoxes. W. J. Humphreys, U. S. Weather Bureau. 2nd ed. 126 p., 2 fig., 18 pl., 13×19 cm. *Williams & Wilkins*, $2. This novel little book by the author of the well-known *Physics of the Air* appeared first in 1923. It contains a collection of those weather proverbs that are known to be essentially correct, with nontechnical explanations of the physical causes which justify them and many hints on how to sense changes in the weather. Simple explanations are given of such paradoxes as: more air goes up than ever comes down; the nearer the sun, the colder the air; the hotter the sun, the colder the earth; the colder the air, the thinner the ice.

Intermediate Textbooks

Experimental Physics. G. F. C. Searle. 363 p., 129 fig., 14×22 cm. *Cambridge Press* and *Macmillan*, $4.50. Accounts of 34 precision experiments in mechanics, surface tension, viscosity, heat and sound used in instruction at the Cavendish laboratory, where the author has served as demonstrator for nearly fifty years. Each section is prefaced by a chapter on theory. The carefully designed apparatus and methods are described in considerable detail, and sample data and calculations are given. Elementary calculus is employed. There is no index.

Sound. E. G. Richardson, Lecturer in Physics, Armstrong College, University of Durham. 2nd ed. 319 p., 111 fig., 14×22 cm. *Longmans, Green*, $5.50. Chapters on impedance, supersonics and the reproduction of sound have been added to the present edition of this textbook on experimental and applied acoustics. Elementary calculus is assumed. The number of references to the literature is unusually large.

Textbooks and References for Upper Division and Graduate Courses

Introduction to Atomic Spectra. Harvey Elliott White, Assistant Professor of Physics, University of California. 457 p., 263 fig., 123 tables, 15×23 cm. *McGraw-Hill*, $5. This presentation of the theoretical aspects of atomic spectra is more detailed and complete than usual, and it requires of the student less maturity in physics. Half of the book deals with one-valence-electron atoms; the remainder, with complex systems. Modern quantum theory is introduced comparatively early, and the orbital model and quantum-mechanical atom are compared at intervals throughout the book. Each chapter contains problems. There are many original diagrams and excellent reproductions of spectrograms.

Theoretical Physics. Georg Joos, Professor of Physics, University of Jena. Trans. from 1st Ger. ed. by Dr. Ira M. Freeman. 748 p., 158 fig., 15×22 cm. *Stechert*, $6.50. An ably translated, modern and remarkably clear treatment that is both intensive and extensive in character, and thus valuable as a general reference work as well as a textbook. There are seven sections: a mathematical introduction; mechanics; field theory; electricity; thermodynamics; statistical theory of heat; and atoms, molecules and spectra, including quantum mechanics. Some of the material is presented in the form of exercises, with hints for solution.

Physics Teaching

Report on the Teaching of Geometrical Optics. Committee of the Physical Society (London). 86 p., 21 fig., 18×27 cm. *Phys. Soc., London*, paper 6/3. This excellent report, made by a distinguished English committee of college, secondary school and industrial physicists deserves careful study. Recommendations are made for the teaching of advanced as well as elementary optics. With regard to the latter the Report suggests, for example, that the early approach to the lens and mirror should be along experimental lines, and that the student should be given a sound conception of the main phenomena of image formation before mathematical formulas are introduced; too often the beginning and end of elementary optical instruction are bound up with $(1/v)-(1/u)=1/f$. Among the topics that can be dealt with experimentally and without the introduction of mathematical difficulties are elementary illumination and photometry and the action of simple instruments like the telescope, microscope and projection lantern. It is pointed out that photometry, because of its everyday importance and educational and experimental value, should receive more attention in the early stages. Studies of the correct illumination for various purposes, and of the proper arrangement of light sources for a given illumination, would provide many experiments without expensive apparatus. We should go beyond the present restriction of experiments on the candlepower of a source in a single direction; this by itself is a measurement of little utility, but once it has been found, one can make the really important determination of the illumination on a screen at a given distance from the source. This can be followed by experiments on the illumination on a screen held in different positions in the room, comparisons of the illumination on a lantern screen and outdoors, etc.

For beginning work the ray treatment is regarded as preferable. It is suggested that the main properties of optical systems will be more readily grasped if curved mirrors are not introduced until the student has mastered the thin lens; this will lessen the difficulty experienced with the signs of distances entering the equations and will render the distinction between object and image spaces and the unbounded nature of each more understandable.

Some of the other recommendations are:

(1) Where convenient, *power*, equal in elementary cases, in air, to $1/f$, should be used in preference to focal length, f.

(2) The power of a converging lens should be called *positive* and that of a diverging lens *negative*, a convention which is now universal among opticians.

(3) The convention of signs should be changed to one of two recommended rules: (a) distances from the lens or mirror are given *positive* values when measured in the *same* direction as the incident light and *negative* values when measured in the *opposite* direction; in view of the convention of the signs of power, the formulas for lens and spherical mirror must then be $(1/v)-(1/u)=1/f$ and $(1/v)+(1/u)=2/r$, respectively; (b) distances measured *along a ray* are assigned *positive* or *negative* values according as the object or image to which they relate is *real* or *virtual;* thus distances are positive if light has traveled along them and negative if it only appears to have done so, a convention which emphasizes the distance between *object space* and *image space;* the one formula $(1/v)+(1/u)=1/f$ here applies both to the lens and to the mirror.

(4) The term "geometrical optics" should be replaced by some such words as *theory of optical instruments*, for it implies a limitation in the treatment of optical theory which should not be allowed to hamper the student. The term *magnification* is regarded as preferable to "magnifying power." One wonders why the Committee did not also recognize the objection to the term "power of a lens"; *strength of a lens* is much better.

It is hoped that an American committee will be formed to study this Report critically in the light of local practices and to make recommendations of a similar nature for optics instruction in this country.

Miscellaneous

A German-English Dictionary for Chemists. Austin M. Patterson, Vice President and Professor of Chemistry, Antioch College. 2nd ed. 411 p., 13×18 cm. *John Wiley*, $3. Since its initial appearance some 18 years ago, few students of physics in this country have been unfamiliar with this exceedingly useful dictionary. The new edition is modern and enlarged. Like the old one, it includes a general vocabulary.

DIGEST OF PERIODICAL LITERATURE

Laboratory and Demonstration Apparatus

A demonstration oscillograph outfit. H. Lloyd; *J. Sci. Inst.* **12**, 119–22, Apr., 1935. A portable oscillograph equipment has been designed especially for class demonstration on the lantern screen. It is inexpensive, produces large diagrams of good visibility, and is adaptable to the reproduction of transients and characteristic curves, as well as periodic quantities. The vibrator unit, time-sweep mechanism and optical system that make up the equipment are described in detail in the article.

Application of a thyratron to induction coils. L. C. Verman; *J. Sci. Inst.* **12**, 167–8, May, 1935. Induction coils fitted with ordinary make-and-break contacts often give trouble due to corrosion and pitting of the contacts. Mercury switches operated by a revolving jet of mercury eliminate these troubles but they are rather expensive. A simple expedient is to utilize a thyratron to switch the current on and off in the primary of the coil, the circuit being similar to the time-base circuits commonly used in cathode-ray oscillographs. This gives sparks of much greater length with about 10 percent of the effective current required for a mechanical made-and-break circuit.

General Physics and Related Fields

Mathematical biophysics. N. Rashevsky; *Nature* **135**, 528–30, Apr. 6, 1935. Until recently there has been no systematic attempt to create a mathematical biology. True, there is a wealth of literature on the application of statistics to biology; but on the whole this field of research has lacked almost completely the physical point of view. Physics is accepted as of paramount importance to biology and the application of its methods has already resulted in important discoveries. But most of this application is restricted to the use of physical apparatus, and little attempt has been made to gain insight into the physicochemical basis of life, similar to the fundamental insight of the physicist in atomic structure. Such insight is possible only by mathematical analysis, through which we must *infer* from the wealth of relatively coarse facts to the much finer, not directly accessible fundamentals. It is frequently said that mathematics is inapplicable to biology because of the tremendous complexity of the phenomena. But this argument really should be used in favor of its application. A simple phenomenon can be understood by "inspection," but mathematical analysis is needed to see through a complex system. The main thing is to be methodologically correct in the application of physico-mathematics, by first studying abstract, over-simplified cases and afterwards gradually taking the complexities into account. Violation of this rule results in failure and has contributed to a skeptical attitude toward mathematical methods.

The author gives a brief review of his own researches to illustrate the fruitfulness of a mathematical approach to biophysics. He begins by defining an abstract, ideal cell. deduces the existence of a system of forces within and without it, and investigates the possible effect of these forces on the cell itself and on neighboring cells. This leads, for example, to a mathematical theory of nervous functions and it accounts in a general way for the various stages of embryonic development and for the forms of various classes of animals. Having thus started from a study of an ideal cell, one has arrived deductively at a possible understanding of such problems as "why we behave as we do" and "why we are shaped as we are."

It is pointed out that the problems discussed here are entirely independent of the mechanism-vitalism issue. Whether present-day physics will prove sufficient for an exhaustive explanation of life, or whether new principles must be introduced in the future, the treatment of those problems necessarily will be mathematical, if it is to be exact and scientific. Physics has inspired many discoveries in mathematics; the time has come when mathematicians may find their problems in the realm of living nature.

Scientific investigation of works of art. P. D. R.; *Nature* **135**, 568–9, Apr. 13, 1935. Great progress has been made in the physical investigation and characterization of paintings but unfortunately there has been some sensational newspaper publicity that has tended to suggest that all manner of questions, including the thorny problem of attribution, can be settled rapidly and with certainty by scientific means. The publicity accorded to the occasional detection of art forgeries by examination with x-rays, and with ultraviolet and infrared radiation, has led many a layman to believe that such methods invariably reveal hidden features of deep significance. In practice, nine out of ten paintings, on x-ray examination, show nothing of significance—or, at least, nothing that can be interpreted with certainty at the present stage of experience. The outstanding difficulty in investigations of this kind is that establishing a satisfactory control experiment—a norm for comparison.

History and Biography

Humphrey Davy's experiments on the frictional development of heat. E. N. da C. Andrade; *Nature* **135**, 359–60. Mar. 9, 1935. Many textbooks cite certain of Davy's experiments as constituting early but important proof of the dynamical theory of heat. Some say that Davy rubbed pieces of ice together in a vacuum; others say that he first made the experiment in air, and then in vacuum.

A little thought will reveal the difficulty, if not impossibility, of obtaining a convincing result with this experiment. If the ice contains a film of water, the friction is so small that scarcely any work is done; if it is really dry, it is liable to stick. In any case, a normal force is needed to hold the two surfaces together, and then one gets a lowering of freezing point and consequent melting, if the surroundings are at the ice point, with possible regelation at the edges. Again, the heat of fusion of ice is large: the criterion is an extraordinarily insensitive one. All these difficulties perhaps may be summarized in the fact that nobody, apparently, has ever tried to repeat the experiment.

It is worth noting that these experiments were among Davy's first contributions and were published when he was only 20 years old. In his 300-word description of the first experiment, Davy says that he fastened pieces of ice by wires to two iron bars and that "by a peculiar mechanism" the ice was kept in violent friction for some minutes. The ice was "almost entirely converted into water" which, strangely enough, was found to be at 35° "after remaining in an atmosphere at a lower temperature for some minutes," or, in other words, the friction of ice can raise water many degrees above the melting point! A simple calculation will reveal that the pressure holding the pieces of ice together would have to be several atmospheres. The experiment is fantastic. No doubt the whole effect observed by Davy was due to conduction.

The second experiment, the one in vacuum, was not concerned with ice at all, but with wax. The wax apparently was attached to a metal plate, against which rubbed a clockwork-driven wheel. The clockwork stood on a piece of ice in which was cut a channel containing water, and the whole was under an exhausted bell jar. The argument was that if the heat required to melt the wax had passed from the ice to the clockwork, the water would have frozen. As, however, the heat needed to produce the rise in temperature observed in the clockwork amounted only to 12 cal., only 0.15 cm^3 of water would have frozen, which actually could not have been observed by eye in this experiment. The experiment proves nothing at all.

It does not detract from the greatness of Davy to point out that his first experiments, carried out in 1799 while he was still a country lad, were uncritical and lacked all quantitative basis. But it is time, however, that they cease to be ranked with such convincing demonstrations as those of Rumford, and disappear from the textbooks.

Reminiscences of Röntgen. J. P. DONAGHEY; *Radiography and Clinical Phot.* **10**, 2-7, Nov., 1934. The author, who is on the faculty of Incarnate Word College, San Antonio, Texas, studied for the doctorate under Professor Röntgen. Later he returned to Munich for post-graduate study and in the year before Röntgen's death, met him frequently and was a guest in his home.

It has been said that the discovery of x-rays was purely accidental. Of course, a discovery so revolutionary as this must necessarily contain some element of chance; one cannot deliberately set out to discover what is absolutely unknown. But Röntgen's achievement did not consist merely in the chance observation of that glowing fluorescent screen. He determined the source of the rays; and so thoroughly did he investigate their properties that very little advance was made upon his findings for 17 years, despite the fact that the best minds everywhere were attempting to solve the problem of their nature. True, considerable progress was made in their application to problems of pure science and great technical improvements were effected in the methods of their production and application in diagnosis and therapy. But it was not until 1912 that the nature of the rays and their location in the spectrum were definitely determined. It was fitting, too, that the theoretical and experimental investigations which led to this latter discovery should have been carried out in the Physical Institute at Munich, of which Röntgen was then director.

Röntgen was born in Lennep, a small town in the lower Rhineland, on March 27, 1845; spent part of his boyhood with relatives in Holland; studied at the Technical High School in Zurich, Switzerland, where he obtained a diploma in engineering; and subsequently secured the doctorate from the University of Zurich. He occupied the positions of tutor and assistant professor at Würzburg, Strassburg and Giessen, and was appointed professor of physics at Würzburg in 1888. Here, in November, 1895, he made his famous discovery. He was called to Munich as head of the Physical Institute of the University in 1900, and in 1901 received the Nobel prize for physics—the first time it was awarded. He resigned his professorship in 1920, and died in Munich, February 10, 1923, within a few weeks of his 78th birthday.

In appearance, Röntgen was a fine type of manhood. He was tall, with broad shoulders, deep chest, flowing beard, bushy hair, and penetrating but kindly blue eyes surmounted by a high forehead. There was none of the slovenliness so often associated with the absent-minded professor. Without any suggestion of foppishness, he appeared well groomed and tailored. This, combined with a fine physique and an athletic litheness acquired during many summers of hiking and mountain-climbing and strenuous seasons of hunting, made him an outstanding figure in any assembly. However, he shunned public gatherings. This was not because of pride, as some have hinted, for he was a man of sincere intellectual humility, an unspoiled hardworking professor, whose innate modesty made everything in the shape of cheap publicity distasteful. Fame came to him unsought. Universities and scientific societies vied with one another in conferring on him the highest honors in their gift, and he was one of the few great men who have had public statues erected in their honor during their lifetime. Evidence of Röntgen's indifference to wealth as well as fame is found in the fact that he died poor. As proof of this, one of his executors said that there was a question of having to dispose of his library—which he willed to the University of Würzburg—in order to meet expenses and a few modest liabilities. Yet Röntgen might have become wealthy through the discovery of the x-rays, for he fully realized their possibilities for medicine and surgery. In fact, he announced his discovery to the medico-physical society of Würzburg in three memoirs which are models of scientific precision and reserve, and which gave all the essential facts—illustrated by radio-

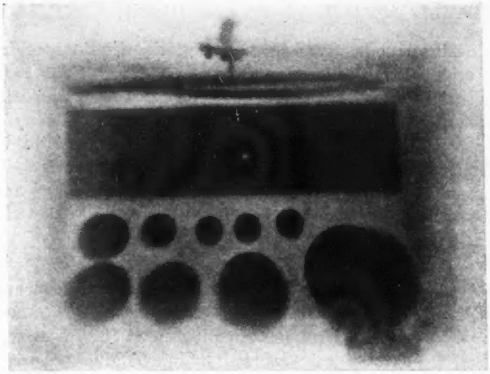

FIG. 1. One of Röntgen's first radiographs. showing a set of weights in a wooden box. (Courtesy of University of Würzburg and *Radiography and Clinical Photography.*)

graphs—regarding the properties and medical possibilities of the new rays. The fact that he sought no monetary gain from his discovery deserves to be widely known, for it establishes his claim to be regarded, in a very real sense, as one of the greatest benefactors of mankind.

Before the War, Röntgen lived in a villa beautifully situated on the right bank of the Isar, which he occupied through the courtesy of the owner, a Bavarian prince. But, owing to post-war conditions he had to vacate this residence. This, together with the death of his wife, to whom he was greatly devoted, made the closing years of his life rather sad and lonely. His conversations toward the end often turned on the subject of the uncertainty of the post-war prospects for Germany; the only trace of bitterness he betrayed was in reference to the occupation of the Ruhr territory and his beloved Rhineland by the Allied forces, an act which he regarded as not only unjust but infamous. But he did not waste his time in idle broodings. To the end, he retained a private laboratory at the Physical Institute, and there he continued his researches until within two days of his death. So great was his industry and interest in this work that his successor, Professor Wien, used to say that he should not be surprised to find Röntgen any day making the announcement of another sensational discovery.

Röntgen's introductory courses of lectures, in which he covered the whole field of physics, usually were attended by about 600 students. While he was not a brilliant speaker, his lectures were marked by that order and clarity which characterized all of his work. Before each lecture he placed on the blackboard in clear and careful handwriting the chief points and principles to be discussed. He used no notes except a few scraps of paper, which he extracted from different vest pockets and used in the mathematical calculations. In his experimental demonstrations, everything went with clockwork precision and after each lecture he usually spent a full half-hour explaining additional experiments that were suitable only for individual observation; this was often the most interesting and instructive part of the lecture. When, in the course of his lectures, he came to the subject of his own rays, Röntgen received an ovation from the class. Throughout the prolonged handclapping and footstamping, he looked rather bewildered and ill at ease, and his treatment of the subject was impersonal and even brief, as if he were anxious to get it over. He did not even show to the class the original pieces of apparatus with which he made his discovery. Later, however, when the new German Museum at Munich was being equipped, Röntgen called the author into his office one day to see the simple but historic outfit—a small pear-shaped Crookes tube darkened by use, an induction coil of the early Ruhmkorff type, and a small, white cardboard screen coated with a layer of fluorescent substance, which he was about to send to the Museum at the request of the directors.

For the privileged few who engaged in research under his direction, Röntgen had no special office hours, but was always ready to assist by his suggestions and advice. In

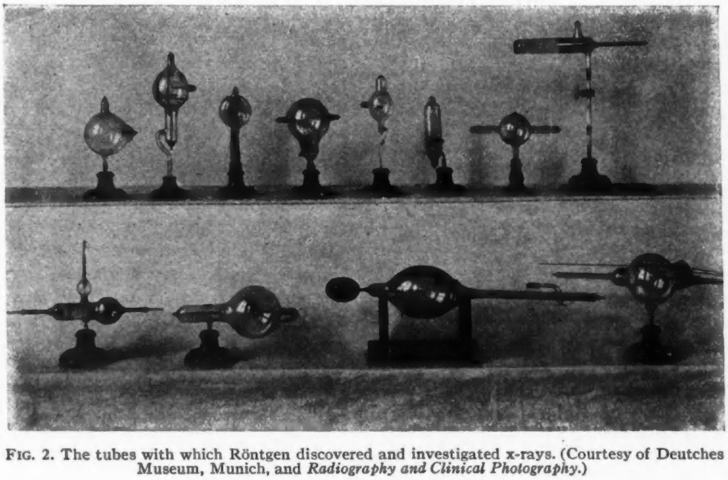

FIG. 2. The tubes with which Röntgen discovered and investigated x-rays. (Courtesy of Deutches Museum, Munich, and *Radiography and Clinical Photography.*)

the moments of discouragement that come to the beginner, when everything just seems to go wrong and every effort seems fruitless, Röntgen proved himself a source of real inspiration and encouragement; without unduly interfering with their own initiative, he had the happy faculty of leading his students from aimless bypaths back to the road which led to results. His criticisms were always helpful and never unkind. One instance which illustrates his thoughtfulness also throws an amusing sidelight on the little foibles sometimes found in the characters of great men. It was the general opinion among the students that at the *examen rigorosum*, Adolf von Baeyer, the famous chemist then head of the Chemical Institute at Munich, was particularly severe on those majoring in physics. Consequently, few chose chemistry as a minor. When the author decided upon chemistry as one of the two minor subjects, Röntgen smilingly mentioned this fact by way of friendly warning. However, when the day of the examination arrived, even the chemistry part of it did not prove to be quite so "rigorous" as anticipated. For a few minutes in the beginning, the examiner was somewhat stiff and hostile, because, due to a little flurry on the part of the candidate, and still more perhaps to a "foreigner's" lack of clarity in expressing himself in German, there was a misunderstanding over some elementary question. But as the examination proceeded, matters improved. The relations between examiner and candidate became quite friendly and they parted on the best of terms. Indeed, the examiner completed the interview long before the end of the allotted period with the remark: "*Gut, ich bin zufrieden*." This was regarded on all hands as a considerable concession on the part of von Baeyer to "one of Röntgen's students"! All the same, it was a rare advantage to have taken work under the "grand old man" of German chemistry who, at eighty, was still active and whose lectures were so full of interest and solid instruction.

Of the many students who came from every land to attend Röntgen's lectures, not even the most sensitive could say he ever heard him utter a word that jarred with his religious convictions. He was not the man to interlard his lectures with cheap sneers about one's beliefs and ideals; of him might be said, as someone said of John Stuart Mill, that his only prejudice was hatred of all prejudice. On the occasion of Röntgen's funeral, at which the author was present, the pastor of the Lutheran Evangelical congregation, of which Röntgen was an active member, bore public testimony to his estimable character as a true Christian gentleman. The funeral cortege was a veritable congress of scientists: physics was represented by outstanding exponents like Planck; and the medical profession, by prominent members like Sauerbruch, the world-famous surgeon. On that gloomy February morning of drizzling rain, while listening to the sincere panegyrics of Röntgen's distinguished colleagues, one had the conviction of assisting at the passing of one of the World's great men.

Physics Teaching and Science Education

Status of college and university offerings in the teaching of science. H. Breckbill; *Sci. Ed.* **18**, 221–5, Dec., 1934. A study of the offerings of 138 colleges and universities showed that 61 percent offered courses in the teaching of science. In institutions having 3000 or more students, 78 percent had such courses. Altogether, 150 courses were offered, of which 11 were in the teaching of physics and chemistry, 21 in the teaching of chemistry and 38 in the teaching of science in general.

A single-period laboratory, a demonstrated success. H. C. Krenerick; *Sch. Sci. and Math.* **35**, 468–76, May, 1935. In the North Division High School, Milwaukee, where the entire physics course is built around 90 quantitative experiments performed by the students, the single period for laboratory has proved to be highly successful. It provides perfect correlation between laboratory and classroom, and also makes it possible to require outside preparation for the laboratory work. Experience shows that substantial experiments of about the same length as those given in the standard manuals can be performed and written up in 45 min. under the following conditions: (1) Have the laboratory work precede the classroom discussion so that student interest in the experiments will be keen. (2) Make the instructions clear and positive in meaning, and include with them *photographs* of the assembled apparatus; compel outside preparations for the experiments by omitting from the instructions a complete discussion of the related subject-matter contained in the textbook. (3) Use simple apparatus and for most of the experiments have enough of it for the entire class to work individually and on the same experiment; spend more money on the laboratory and less on demonstration pieces, which are expensive. (4) Simplify the student's reports to include only data, computations and conclusions, written up according to some uniform system so that they can be graded quickly at the close of the period.

The author has found in his long experience no better method than this for covering the material in the text completely and thoroughly; with about half as much time spent on the class drill as formerly, the grades have increased decidedly. He says "I used to think, with many others, that physics was too difficult a subject for students to prepare with their own efforts, and consequently presented it by demonstration and class discussion. A short time ago a former student told me how he enjoyed physics. He said that I made things so clear that he never had to spend more than ten minutes on the subject. I suppose that he was paying me a compliment, but to me it was a severe criticism of my methods. I was glad that I could tell him that I was no longer teaching physics that way, that the students were now doing the work and that I had the ten-minute end of the job."

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